PLATE I

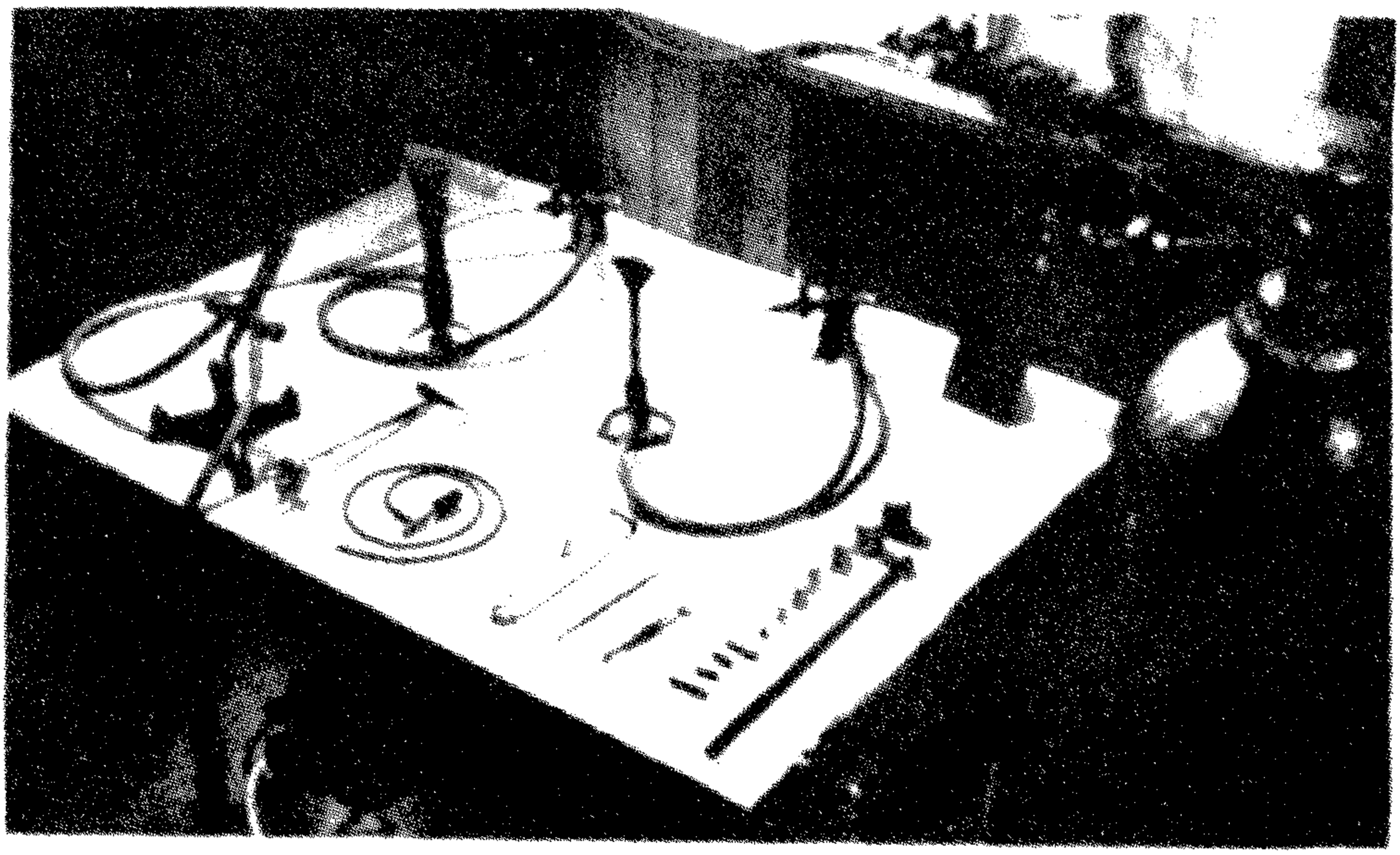

FIGURE 1

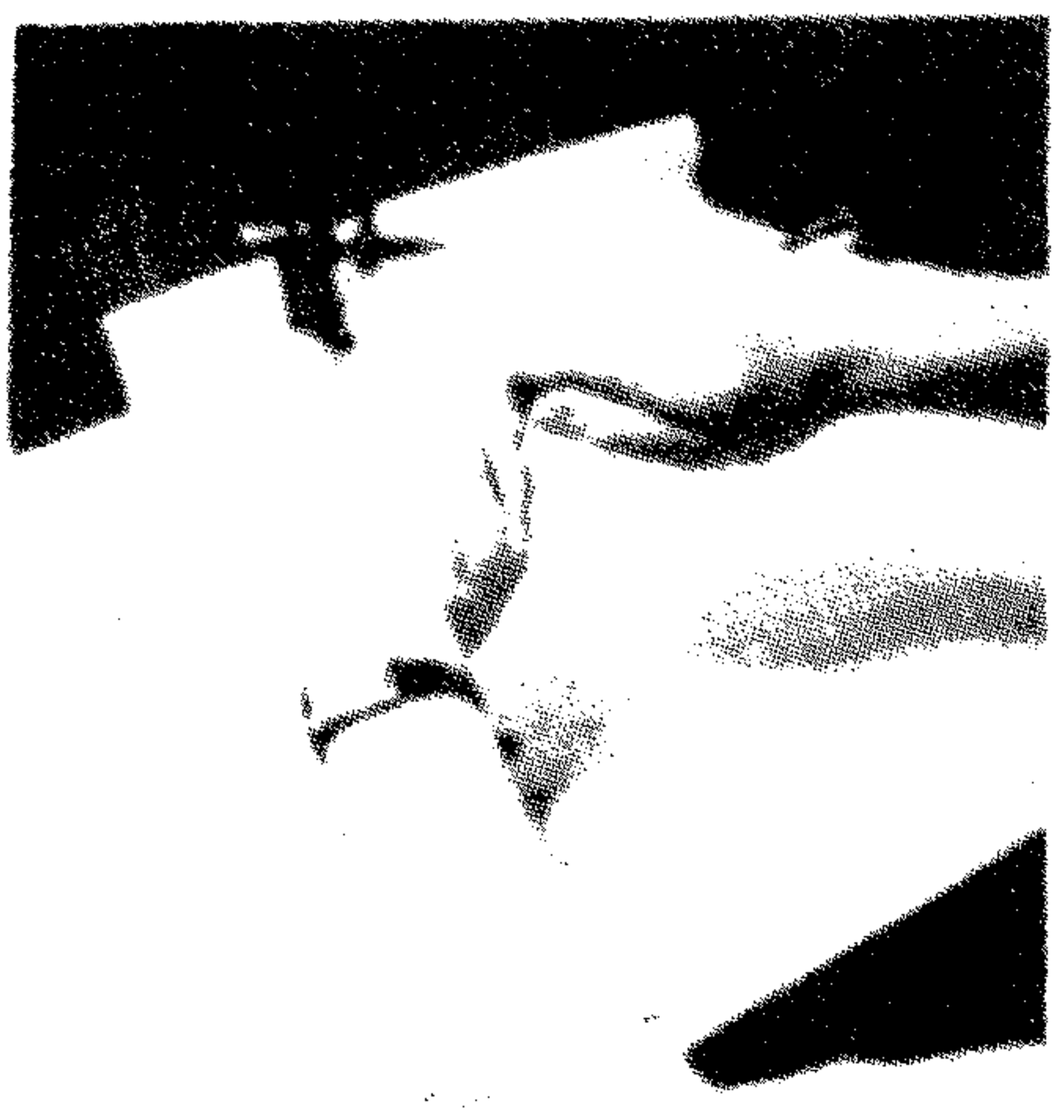

FIGURE 2

FIGURE 3

Manual of
LABORATORY
GLASS-BLOWING

By

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INTRODUCTION

LABORATORY glass-blowing, like most arts, tends to change its objectives and methods in response to changing demands on its practitioners and changing resources open to them. Whereas many of the manuals of the past dealt extensively with the making of such things as stopcocks and even thermometers, and had little or nothing to say of the apparatus used in, for example, vacuum work, it is now possible to buy many of the things that formerly had to be made; and the laboratory glass-blower is more often called upon to produce special apparatus for special purposes. The operations described in this book reflect this change.

The first two chapters give a short and, as far as possible, non-technical account of the materials, glass and gas, used by the glass-blower, and are intended to answer most of the "whys" in the later chapters.

Chapter 3 describes the tools that are required for ordinary work around a physical or chemical laboratory. No attempt has been made to compile a complete list of all the equipment that it is or might be desirable to have. The most important tools of all—the glass-blower's brain and hands—will make up for much; and by starting with a limited assortment such as is shown

in Plate I, Figure 1, and exploring its possibilities fully, the worker will be able to appraise at their real value the many tools and accessories listed in the apparatus catalogues. Where a catalogue reference is given in connection with any piece of equipment, the author intends simply to indicate the sort of thing that is required. He makes no pretence of suggesting that the device referred to is necessarily superior to all others.

Chapter 4 outlines the fundamental operations which form the basis of all that follows. It is hoped that the descriptive matter when taken in conjunction with the photographs will enable the beginner to "start from scratch." Nevertheless, no written directions can ever be an adequate substitute for personal instruction, and the beginner should always try at least to watch a glass-blower at work. A visit to a Neon Sign factory, if it can be arranged, will be well worth the time and trouble involved.

The instructions given for the more advanced operations in the later chapters are written with the presumption that the techniques of Chapter 4 have been thoroughly mastered and that the worker is able to visualize for himself the results aimed at and the minor details of the operation.

The choice of what to include among the more advanced operations was a difficult one and the final selection was based primarily on the things the writer has had to make at one time or another. A number of operations that ought, perhaps, to have been included have nevertheless been omitted because they lie outside the writer's own direct experience. It is hoped that these

omissions will be made up for by an increased clarity in the rest.

In conclusion, the writer wishes to acknowledge his indebtedness to all those who have, at various times and places, shown him most of the tricks which go to make up this book.

R. H. W.

Fredericton, N. B., Canada.

PLATES

PLATE PAGE

I. . . . . *Frontispiece*

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CHAPTER I

GLASS

In this chapter we shall consider those properties of glass which are of interest to the laboratory glass-blower.

In addition to being inert and transparent, glass is a non-crystalline, vitreous substance, and this fact is largely responsible for its usefulness in the laboratory and elsewhere. When crystalline materials are heated, they either decompose or melt sharply at a well-defined temperature. Ice, for example, remains solid and rigid as its temperature is raised until, at 0°C., it begins to melt and form liquid water which coexists along with some still-solid ice. Glass, on the other hand, becomes gradually softer and more plastic when it is heated, and there is no particular temperature at which we can say that it has begun to melt. In other words, glass is comparatively rigid at the ordinary temperature and comparatively fluid at high temperatures, and passes through a plastic stage in between, and as there are no well-defined temperature boundaries to the plastic stage glass is sometimes regarded as being a highly viscous liquid even at low temperatures.

The operations of glass working depend on these properties because the glass can be heated until it becomes soft enough to be worked into the desired shape and then allowed to cool until it regains its rigidity and can retain its shape indefinitely. But the very gradualness with which the plasticity is gained and lost makes it necessary to observe certain precautions if the piece is to have the necessary strength.

Picture what happens when an irregularly shaped lump of glass is allowed to cool after being heated well into the plastic range.

First of all, the thin places cool and become rigid while the thicker parts are still hot and plastic. Because the thin places have cooled more they have also contracted more, and this unequal contraction produces stresses (i.e. forces) which are relieved by the deformation of the hotter parts. Next, the outer layers of the thicker parts become rigid and this process of yielding to the unequal contraction is repeated inside the thick parts. Then the whole piece becomes rigid while there still remain temperature gradients within it. Finally, as the cooling continues and the temperature tends toward uniformity, the hotter parts contract more than those that have already cooled, but the glass can no longer flow so as to relieve the resulting stresses, and the piece is left in a state of internal strain.

If the strains are serious, the glass may shatter in order to relieve them—which is what happens when a piece of hot glass is plunged into cold water. Sometimes the shattering is delayed for hours or days and the failure may be limited to no more than a few cracks

which develop spontaneously or as a result of some mechanical shock. The net effect is, however, that the piece lacks mechanical strength. Moreover, even if the piece does not crack during the process of cooling or afterward, it may crack when it is re-heated, for then the above sequence of events is reversed as the thin places and outer layers begin to expand before the rest, and a whole set of new forces is added to the old ones.

To sum up, a piece of glass which is thick, or has thick parts, is placed in a condition of strain when it is cooled from a high temperature, the strain being due in part to plastic deformation at the beginning of the cooling and to unequal contraction during the later stages. As a result of these strains, the piece is easily broken by either mechanical or thermal shocks.

Hence, in order to produce a piece of adequate strength, strains must be kept at a minimum, and this is accomplished by a combination of three methods:

1. Abrupt inequalities in thickness are reduced as much as possible by proper blowing, as in Plates III and V. If the glass is uniform it will cool uniformly, and if it is not too thick the temperature gradients will not be great enough to produce serious strains.

2. The rate of cooling can be made small so that steep temperature gradients and large inequalities in contraction can not arise. This is called annealing.

3. The composition of the glass may be made such that its coefficient of thermal expansion will be small. The ill effects of unequal cooling are then less important.

Since the later chapters are concerned with the tech-

nique of blowing out inequalities in thickness, the discussion at this stage will be limited to annealing and to a short account of the types of glass commonly met with.

Glass is annealed by heating it until it is plastic enough for its internal stresses to be relieved, and then cooling it so slowly that no steep temperature gradients can be set up. In bottle-factories this is done by passing the ware through tunnel furnaces in which the temperature varies slowly from point to point. In the laboratory, an annealing furnace may be used, although the writer has never felt the need for one. However, if apparatus with unavoidable and large variations in the thickness of the glass has to be made from lime-soda glass, the annealing may have to be done in a furnace. Any furnace will do provided it is large enough to hold the piece and can be heated to the requisite temperature and thereafter cooled sufficiently slowly. A simple annealing furnace can be made by wrapping a length of stove pipe with sheet asbestos, winding it with electrical resistance wire, and covering it with about three inches of loose asbestos or other insulating material.

Relatively simple joints such as are shown in Plate III, Figure 1, and in Plate IV, need very little annealing. It is generally sufficient to heat them all round until they begin to color the flame yellow, and then leave them to cool quietly in a place that is free from draughts. Joints like those shown in Plate III, Figure 2 or in Plate V, can be annealed by heating them all round until they color the flame and then rotating them in a large luminous flame until they are well covered

with soot, after which they are left to cool quietly. Still more complex pieces, like those shown in Plate VIII, after being well covered with soot, should be wrapped in cotton wool in order to reduce the rate of cooling still further.

These rules apply to apparatus that is made from "soft" glass, that is, lime-soda or lead glass, which has a relatively large coefficient of expansion. With such glass and the glass-blowing facilities available in the ordinary laboratory, it is almost impossible to make pieces like those shown in Plate IX.

Because of its smaller thermal expansion, borosilicate glass needs less annealing and the foregoing rules can all be moved back one or two stages, that is, the wrapping with cotton would be necessary only with the most complex pieces in Plate IX.

Fused quartz, which has an extremely small coefficient of expansion, needs little or no annealing and can, indeed, be cooled from incandescence with cold water without cracking.

The amount and kind of annealing that is required depends on the kind of glass being used, the skill of the glass-blower in removing or avoiding sudden variations in thickness, and the amount of residual strain that is permissible.

It will be seen from the account of what happens when a hot lump of glass is cooled quickly, that the greater part of the strain is due to plastic deformation of the hot parts brought about by the contraction of those that have already cooled. Hence, if the piece is cooled slowly until it has all become comparatively

rigid, the cooling can thereafter be speeded up quite considerably without any serious permanent strains resulting, although there may be serious temporary strains due to the unequal contraction during the cooling. These will largely disappear when the temperature once more becomes uniform.

The terms "softening point" and "annealing range" can of necessity only be given arbitrary definitions.

Thus, a piece of glass tubing clamped horizontally at one end will sag slightly and acquire a permanent "set" after a period of years. A thermometer whose bulb is maintained at a temperature of one or two hundred degrees for some hours will not give a correct reading at 0° when it is once more cooled. These and other phenomena show that glass retains a measure of plasticity right down to room temperature. Similarly, a horizontal glass tube heated in a furnace will collapse sooner if it is evacuated and subject to the pressure of the atmosphere than if it is simply left to collapse under its own weight.

The softening point of glass must be considered in relation to the thickness of the piece and the amount of residual strain that can be allowed. In order that different varieties of glass may be compared, an arbitrary softening point has been defined as the temperature at which a glass rod 1 mm in diameter and 225 mm long will elongate under its own weight when suspended vertically, at a rate of 1 mm per minute. For most purposes, the annealing range can be taken as extending somewhat less than three hundred degrees (Centigrade) down from the softening point. Once

cooled out of the annealing range, the glass does not acquire any serious permanent strains from temperature gradients set up in it.

Since glass is not a chemical individual but rather a complex mixture or solution of a number of compounds, there are a great many different kinds of glass on the market, each of which has properties that determine the use to which it is put. Lamp-blown glass generally belongs to one of the types whose composition is given in the following table.

SOME TYPICAL GLASSES

	Lead-Glass (Corning)	*Lime-Soda* (Kimble, Standard Flint)	*Borosilicate* (Kimble)	*Borosilicate* (Pyrex)	*Fused Quartz*
SiO_2	63.	67.9	74.7	80.6	100.
Na_2O	7.6	14.7	6.4	4.4	...
K_2O	6.0	1.3	0.5	...	...
Al_2O_3	1.	3.	5.6	2.	...
B_2O_3	...	1.4	9.6	13.	...
PbO	21.	...	...	...	...
CaO	...	5.5	0.9	...	...
BaO	...	2.0	2.2	...	...
MgO	...	4.0	...	...	...
Expansion coefficient per °C.	.0000090	.0000092	.0000049	.0000033	.00000054
Softening point:					
°C.	615	590	655	815	1625
°F.	1140	1100	1210	1500	2960

(The information contained in the above table was supplied through the courtesy of the following manufacturers: The Corning Glass Works, The Kimble Glass Co., and The Hánovia Chemical and Manufacturing Co.)

Of the various types of glass, lead glass is in some ways the easiest to work in the flame. It has a low softening point and is workably plastic over a rather wide range of temperatures, so that a good deal of manipulation is possible after the piece is removed from the flame. For these reasons it is used extensively in making Neon Signs. It is, however, rather easily scratched and is attacked by a number of chemical reagents so that its usefulness in the laboratory is rather restricted. Moreover, unless a strongly oxidizing flame is used, part of the lead is chemically reduced and produces black stains in the joint. They can only be avoided by keeping the glass well out in the tip of the flame and using plenty of air in the blast so that the glass does not come in contact with any hot unburnt gas.

Lime-soda glass because of its greater chemical resistance and nearly as easy workability is much more commonly used in laboratory glass-blowing. The range of temperature within which it is plastic enough to be blown is narrower than with lead-glass, but if care is taken to heat it sufficiently there is no difficulty about producing the simpler types of joints with it. All the pieces shown in Plates I to VIII were made with this kind of glass. Because of its large coefficient of expansion, more complicated pieces are very likely to crack unless they are very carefully annealed, and with the facilities usually available it would be almost impossible to make the apparatus shown in Plate IX from lime-soda glass.

Borosilicate glass, with its lower coefficient of ex-

pansion and still greater chemical resistance, is in many ways the ideal glass for laboratory use. Requiring less annealing, it demands a lesser degree of skill on the part of the glass-blower, and pieces that could hardly be attempted with soft glass are entirely feasible with it. On the other hand, its higher softening point requires the use of oxygen to supplement or replace the air in the blast flame, and it is very important to heat the work very strongly in order to avoid minute pinholes in the joints.

Owing to its cost and the difficulties of working which arise out of its very high softening point, fused quartz is used only where its special properties (such as transparency to ultra-violet light) render it particularly suitable.

It is important to know how to distinguish between the various types of glasses, as owing to their different thermal expansivities it is, for example, impossible to seal borosilicate glass directly to lime-soda or lead-glass without the joint cracking. Lead-glass is, of course, easily identified by its becoming blackened when held in the reducing part of the flame, that is, in the blue inner cone. The only reliable method of distinguishing between lime-soda and borosilicate glass is by comparing their behavior in the flame. To do this, the piece to be tested is heated along with a piece of known type, and when they have become soft they are pressed together and their comparative plasticities tested by pushing and pulling gently. The softer of the two pieces can be drawn out at a temperature at which the harder piece is already practically rigid.

When any kind of glass is heated into its softening range and kept there for some time, a process known as devitrification may take place. When this happens, the surface takes on a frosted appearance and the glass may lose its plasticity, becoming stiff and hard to work. Glass is normally a vitreous (non-crystalline) substance with its various constituents in solution in one another. When devitrification sets in, it appears that some of the components of the glass begin to crystallize and separate out of the mixture which then becomes heterogeneous, and its softening point rises and its other properties are altered. Beginners, who spend a long time making a joint, are often overtaken by this phenomenon. Mild devitrification, appearing only as a slight frosting of the parts which have been heated the most strongly, will do no harm, but a badly devitrified part must be cut out and discarded. Some varieties of glass devitrify more easily than others, and old glass is more likely to do so than new. Also, glass that has been exposed to water for a long time, or to alkaline solutions, will tend to behave in the same way.

Because of their high softening points, the borosilicate glasses and fused quartz can not be worked in the ordinary blast flame using a gas-air mixture, and hence a gas-oxygen or a gas-air-oxygen mixture is required. Much depends on the properties of the fuel gas. Thus; borosilicate glass can be worked with acetylene-air mixtures, while even with pure oxygen it may not be possible to work quartz if the gas is of low calorific value.

CHAPTER II

GAS BURNERS

BEFORE proceeding to a description of the various ways in which gas burners are used by the laboratory glass blower, it is desirable to consider briefly the principles on which they operate and the factors that underlie the choice of a particular burner for a particular purpose.

Imagine a stream of combustible gas, like hydrogen or coal gas, burning as it emerges from a plain jet such as might be made from a length of metal pipe or glass tube. The gas can only burn where it is in contact with and to some extent mixed with air, and since the process of diffusion does not take place instantaneously, the gas leaving the center of the jet has to travel some distance before it begins to burn, while the gas near the wall of the jet can burn as soon as it passes the end of the tube. The flame is accordingly tall and "hollow" in that it has a core of cold, unburnt gas which is surrounded by a more or less conical sheath of fire. Such a flame is also luminous, that is, it is yellow in color (unless the gas is pure hydrogen).

Suppose, now, that a certain amount of air is mixed with the gas before it leaves the jet. (This is accom-

plished in the Bunsen and Meker burners by making openings near the bottom of the stack, and through these air is drawn into the rapid stream of gas issuing from the inner orifice.) When the air-gas mixture emerges into the atmosphere and begins to burn, the combustion takes place through a greater thickness of the stream, owing to the head start provided by the air already present. Hence the flame is shorter and hotter because the same amount of heat is being generated in a smaller space.* The flame will, however, still be hollow and pointed because the mixture emerging from the center of the jet has some distance to travel before it enters the burning zone.

In short, the Bunsen burner gives a hotter flame because the combustion is more concentrated as a result of adding part of the air required for combustion to the gas before it leaves the jet.

Suppose, now, we try to add *all* the air required for complete combustion to the gas before it leaves the stack of the burner. In general, one of two things happens. Either the flame "strikes back" and burns inside the base of the burner where the mixing is supposed to take place, or else the opposite happens and the flame "blows off," that is, it rises off the end of the stack and eventually goes out. These things happen for the following reasons:

* Be careful to distinguish between *quantity* of heat (calories or B.T.U.'s) and *intensity* of heat (degrees Centigrade or Fahrenheit). A cubic foot of coal gas will give a certain definite number of calories or British Thermal Units when it is completely burned—no matter how this burning takes place. But if the process of burning is concentrated into a small region of space or time (or both) the *intensity* of the heat will be greater, or in other words the flame will reach a higher temperature.

1. Striking back. The speed with which a flame can advance through a mixture of gas and air depends on the nature of the gas and the amount of air that is mixed with it. For a given kind of gas, the flame velocity reaches a maximum at or near the composition required for complete combustion without excess of gas or air. Clearly, if the speed with which the flame can travel through the mixture is greater than the speed with which the mixture passes out of the top of the burner, the flame will advance down the stack against the current until it reaches the mixing chamber at the bottom.

2. Blowing off. The amount of air required for complete combustion depends on the nature of the gas being burned. If the amount of air required is very large, the gas must enter the mixing chamber at high speed in order to draw in a large amount of air through the openings or ports. Thus the mixture may travel up the stack so fast that the flame can not keep pace with it at the top, and so the burning zone rises clear of the opening and blows off.

Hence, a burner strikes back if the rate of propagation of the flame is too large, and it blows off if this rate is too small, relative to the speed of the gas through the jet. Now it happens that those gases which require the largest volumes of air for complete combustion (and hence the highest speeds through the mixing chamber) are generally those which have the smallest flame velocities. Therefore these are the gases that tend, if anything, to blow off. On the other hand, the gases that require less air (and hence have a slower velocity

through the mixing chamber) generally have a higher flame speed and tend to strike back.

These factors have to be taken into account in selecting a burner for any particular kind of gas. If it requires a great deal of air for complete combustion, the air inlets into the mixing chamber must be large and at the same time the rate at which the mixture travels up the stack must be kept small. If the amount of air required is small, the openings must be small and the velocity of the mixture must be made large. As a rule, the gases that are poor in hydrogen belong to the first type (large air requirement, small flame velocity) while those that are rich in hydrogen belong to the second type (smaller air requirement, higher flame velocity).

The following table shows the composition of three typical fuel gases, together with their calorific values and air requirements.

	Coal Gas	*Natural Gas*	*Bottled Gas*
H_2	57.9%	...	...
CO	6.2	0.1%	...
CH_4	27.0	89.0	...
C_2H_6	...	7.0	...
C_3H_8	...	...	28.7%
C_4H_{10}	...	...	71.3
N_2	3.5	0.5	...
O_2	0.8	0.2	...
B.T.U. per cu. ft.	527.	1100.	3037.
Cu. ft. air per cu. ft. of gas	4.3	10.9	34.6

It will be seen that the air requirement is roughly proportional to the calorific value of the gas. Hence it has become the custom to compare gases on the basis of

to dilute the flame and absorb an appreciable part of the heat of combustion. For still higher temperatures, therefore, oxygen must be substituted for air in the blast.

For some purposes it may be desirable to use a mixture of air and oxygen in the blast, but this requires a more elaborate (and expensive) type of three-inlet burner in which the air and oxygen are mixed before entering the burning zone. With such a burner it is possible to obtain an extremely wide range of flame sizes and temperatures.

CHAPTER III

THE TOOLS

THE glass-blowing equipment used by the writer is shown in Plate I, Figure 1. The work bench is a laboratory table of the usual height, situated in a not-too-well lighted part of the room so that the color and other characteristics of the flame and hot glass can be more easily seen. It is covered with asbestos, and the usual drawers and cupboards have been removed from under it to make room for the foot-operated bellows. In laboratories that are supplied with compressed air, a bellows is not necessary although some glass-blowers still prefer one as giving a more easily controlled air blast.

The blast lamp shown at the left of the figure is a simple type with inlets for gas and air only. More elaborate ones with inlets for both air and oxygen are available and are useful for the more advanced operations. The size and shape of the blast flame must be controlled and adapted to the work in hand. This is done by adjusting the supply of gas and of air or oxygen, by altering the position of the tubular barrel that surrounds the air-jet, and by selecting a jet of the proper size. The lamp is supplied with interchangeable jets of

varying diameter, those not in use being screwed into holes in the base. In general the flame should be a little narrower at its widest part than the outside diameter of the glass tubing being heated, and when later on reference is made to "a flame of the correct (or usual) size," it will indicate a flame that has been so adjusted. The flame should be as far as possible free from yellow luminosity although with some kinds of gas it may be difficult to avoid some color close to the jet. It must be blue at the tip or it will not be capable of heating the glass sufficiently, but the air blast must not be made too strong so that the flame hisses.

With tubing of large size, above 15 to 20 mm diameter, the usual blast lamp will not give a large enough flame even when the largest jet is in use, and in such cases the writer generally directs the blast flame into the flame of a large Meker burner as shown in Plate II, Figure 3.

With very large and cumbersome apparatus it is generally easier to move the flame than the glass, and a hand torch is therefore required. There are a number of different models on the market; the one shown lying beside the blast lamp is a common type and works on precisely the same principle as the blast lamp. A hand torch of radically different type is described later on in Chapter 5.

For bending tubing an ordinary Bunsen burner with a "wing-top" is useful for U-bends and it can be used also for right-angle bends though the writer generally prefers to use the large Meker for the purpose. The width of the opening in the wing-top should be ad-

justed by opening or closing it slightly until the flame is flat or only slightly rounded at the top and is free from jagged points.

Next in line in the figure (Plate I, Figure 1) is the blowing tube. This is simply a length of light rubber tubing provided with a glass mouthpiece at one end and a glass-blower's swivel at the other. The swivel is a most useful gadget whose virtues are not sufficiently well known to many laboratory glass workers. It consists of a small brass T-tube in the cross-piece of which is fitted an inner tube which is free to rotate. The projecting end of the inner tube is provided with a rubber stopper which will fit either inside or outside the tube being worked (See Plate II). The swivel enables the glass tubing to be rotated continuously in the flame without the blowing tube becoming twisted.

The remaining apparatus includes a sharp file, a flint gas lighter, a pair of forcepts or long-nosed pliers, a bit of chalk for marking the glass, an assortment of corks and a few rubber end-plugs. These last are short lengths of rubber tube closed at one end by a small cork or piece of glass rod, and they are used for temporarily closing the ends of tubes that are too small for corks, while they are being blown.

A cylinder of compressed oxygen provided with a pressure-reducing valve is required if borosilicate or quartz glass is used.

A hot-wire glass cutter is also useful.

There are a number of ways of cutting glass tubing, the choice between them depending on the size of the tube and the position of the cut. Tubing of less than

15 mm diameter is cut as follows. With a sharp file make a single clean scratch on the tube. (The file will generally cut better if it is wet.) Then place the thumbs firmly against the tube on the side away from the scratch (as in Plate I, Figure 2) and break the tube by *pulling* it apart and at the same time bending it slightly away from the scratch. The success of the operation depends on making a V-shaped nick in the glass and then producing a stress which, when concentrated at the bottom of the V, will cause the tube to crack off at the desired point.

With tubing of larger diameter or with small tubing which must be cut close to one end, a hot-wire glass cutter can be used. There are various types, the author's being a very simple home made affair. A piece of No. 28 (B. and S.) nichrome or chromel wire about 18 inches long is attached at the ends to two insulated leads through which a current of any desired strength can be sent from a resistance mounted on the wall. A rheostat capable of carrying up to 5 amperes may be used. The author improvised a resistance by connecting a dozen lamp receptacles in parallel and then connecting the whole set in series with the cutting wire, so that the current is increased by screwing in more lamps. A knife switch which can be closed by stepping on a pedal on the floor and which is opened by a spring when the pedal is released, leaves the hands free to manipulate the tube and cutting wire. The bank of lamps can also be disconnected from the wire and used for other purposes (see, for example, Chapter 7). In using the hot-wire cutter, the tube is scratched all round with the file

and the resistance wire is wrapped round once so that it lies in the scratch and the two ends do not quite touch. One of the insulated leads is fastened to the wall and the other is held in the hand so that the wire is pulled tight. (See Plate I, Figure 3.) A current strong enough to heat the cutting wire red hot except where it is in contact with the glass is sent through, and in due course the glass cracks—if it happens to be soft glass. With borosilicate glass it is generally necessary to drop a little water on (say from a wash bottle) after the current has been passing about 40 seconds.

A much more convenient and simple method of cutting large tubing, borosilicate included, involves the use of a special tool with which the tube can be scratched all round on the *inside*. It is then only necessary to rotate the scratched part in the flame for a few seconds to start the crack.

It is sometimes possible to cut tubing successfully by scratching it all round with a file and then suddenly pressing a very small, very hot bead of glass into the scratch.

Whatever method may be used, a jagged point is sometimes left on the end of the tube. If this happens, the sharp points can be smoothed off by striking diagonally across the end of the tube with a piece of wire gauze.

When all else fails, a tube can be "cut" by first closing it completely as shown in Plate IV, Figure 2, and then blowing it open as in Plate III, Figure 2.

CHAPTER IV

FUNDAMENTAL OPERATIONS

I. *Joining Tubes of Equal Size*

This is the fundamental operation whose mastery opens the way to practically every other operation commonly carried out in the course of laboratory glass blowing. The beginner should study and practice the various methods before proceeding to the more difficult operations.

The best sized tubing for the beginner is from 8 to 12 mm outside diameter. Take two pieces of such tubing about 8 inches long, and close one end of one with a cork and attach the other to the blowing tube. Adjust the flame of the blast lamp to give a flame about 3 inches long and a little narrower at its widest part than the diameter of the tubing. Heat the open ends of the tubes. During this heating the tubes must be rotated so they will be uniformly hot all round, and as this is the hardest thing for the beginner to learn, it will be considered here in some detail.

There are a number of ways of holding the tube,

the choice between them depending partly on the size of the tube and partly on the preference of the worker. Some of them are shown in Plate II. In Figure 1, the right hand is in the working position while the left hand has been partly opened to show how the glass is held between the edge of the palm and the last two fingers. The thumb and forefinger rotate the tube while the middle finger steadies and guides it. Figure 2 shows a method that is particularly adapted to small tubing. It will be seen that the tube rests in the fork of the thumb and first finger and is rolled on the *side* of the latter. If the tube is rolled between the thumb and the tip of the index finger it is almost impossible to keep it from wobbling about.

The beginner should use fairly short lengths of tubing so that the forearms can be rested against the edge of the table in order to avoid "end play." With longer pieces, as in Figure 3, it is necessary to hold them in the position shown, and some practice is required before it is possible to rotate the two pieces about the same axis, and at the same rate, and at a constant distance apart.

Returning, now, to the operation of sealing the two pieces together, when the ends have been heated well into the softening range take them out of the flame and press the ends together firmly. A certain amount of squashing of the glass will do no harm and is easier to get rid of than pin holes due to too little squeezing together. Immediately return the joint to the flame and heat it all round. Then concentrate the flame in one spot until the glass has softened and collapsed to about

PLATE II

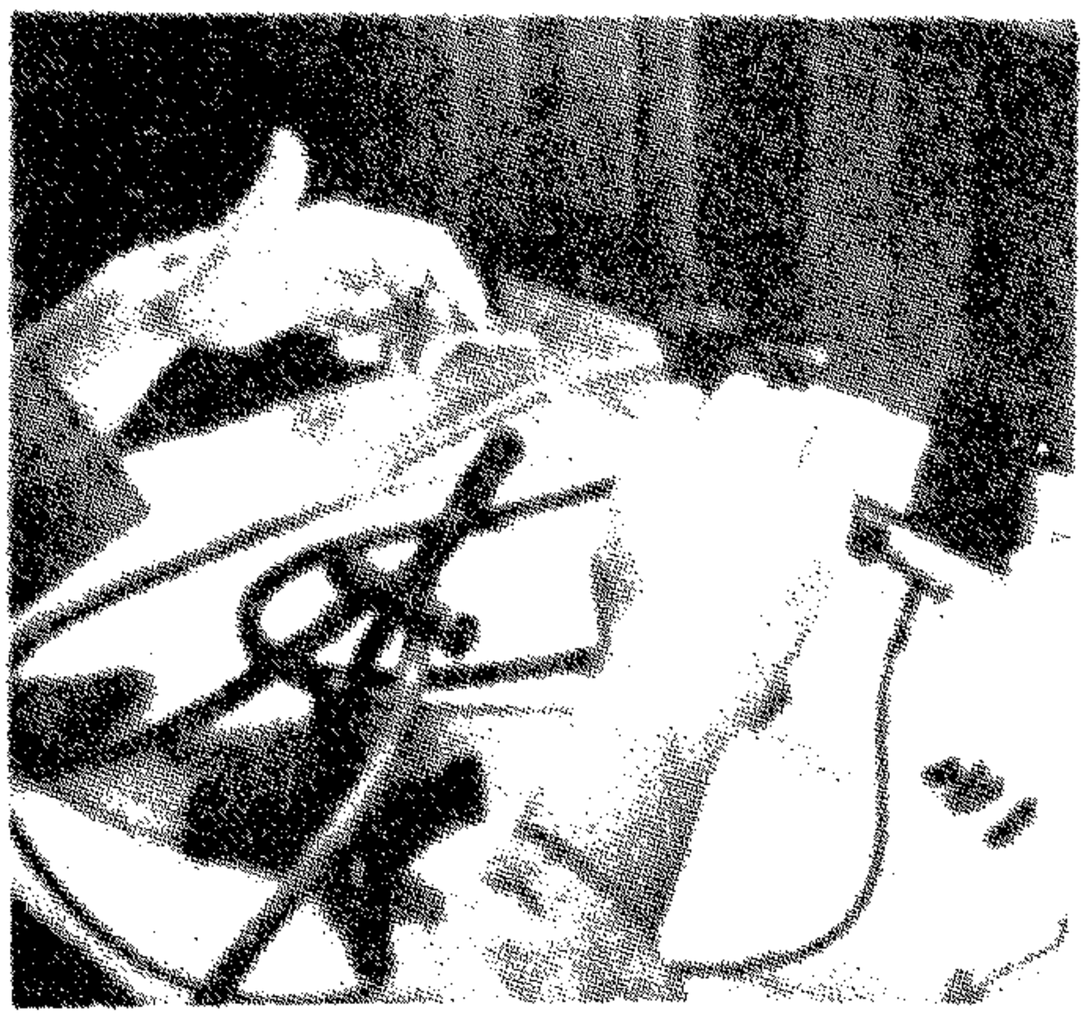

FIGURE 1

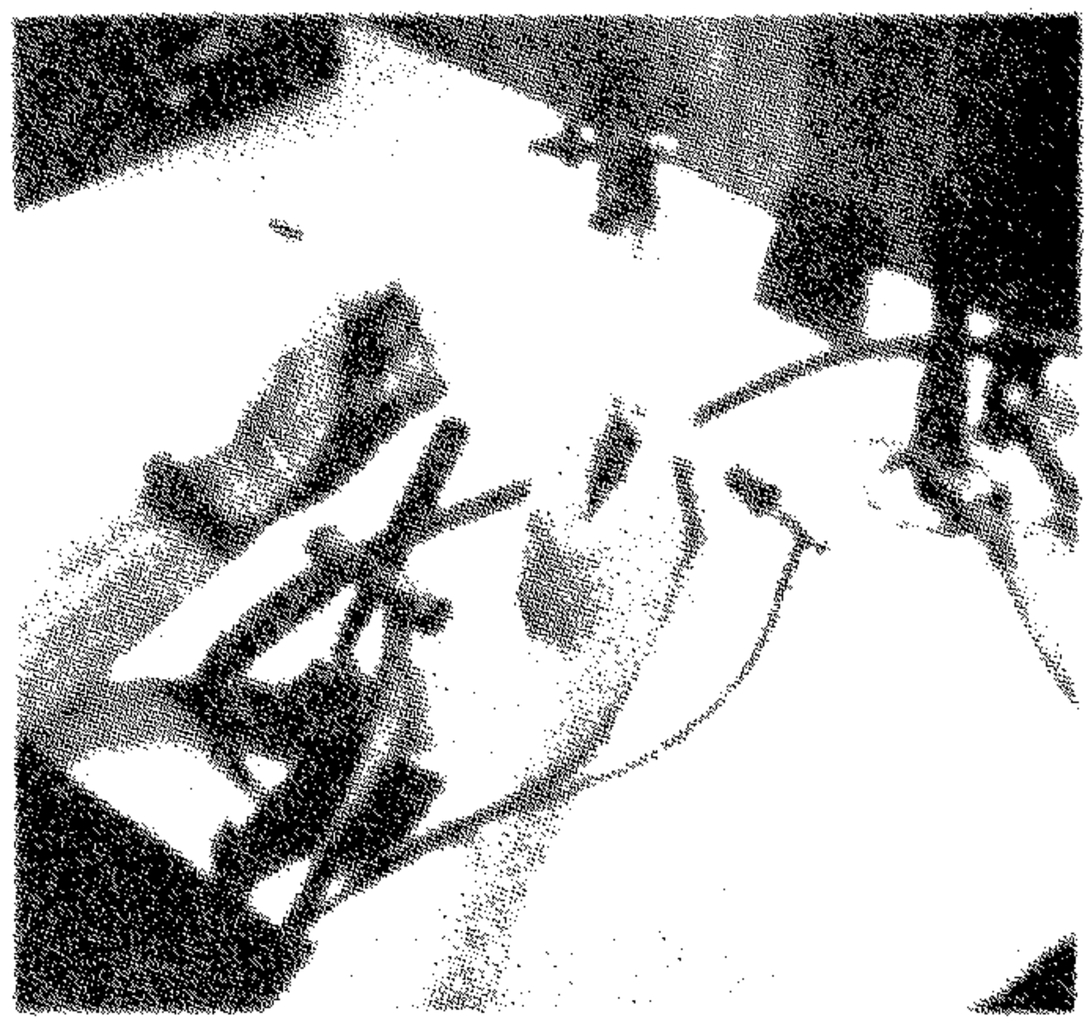

FIGURE 2

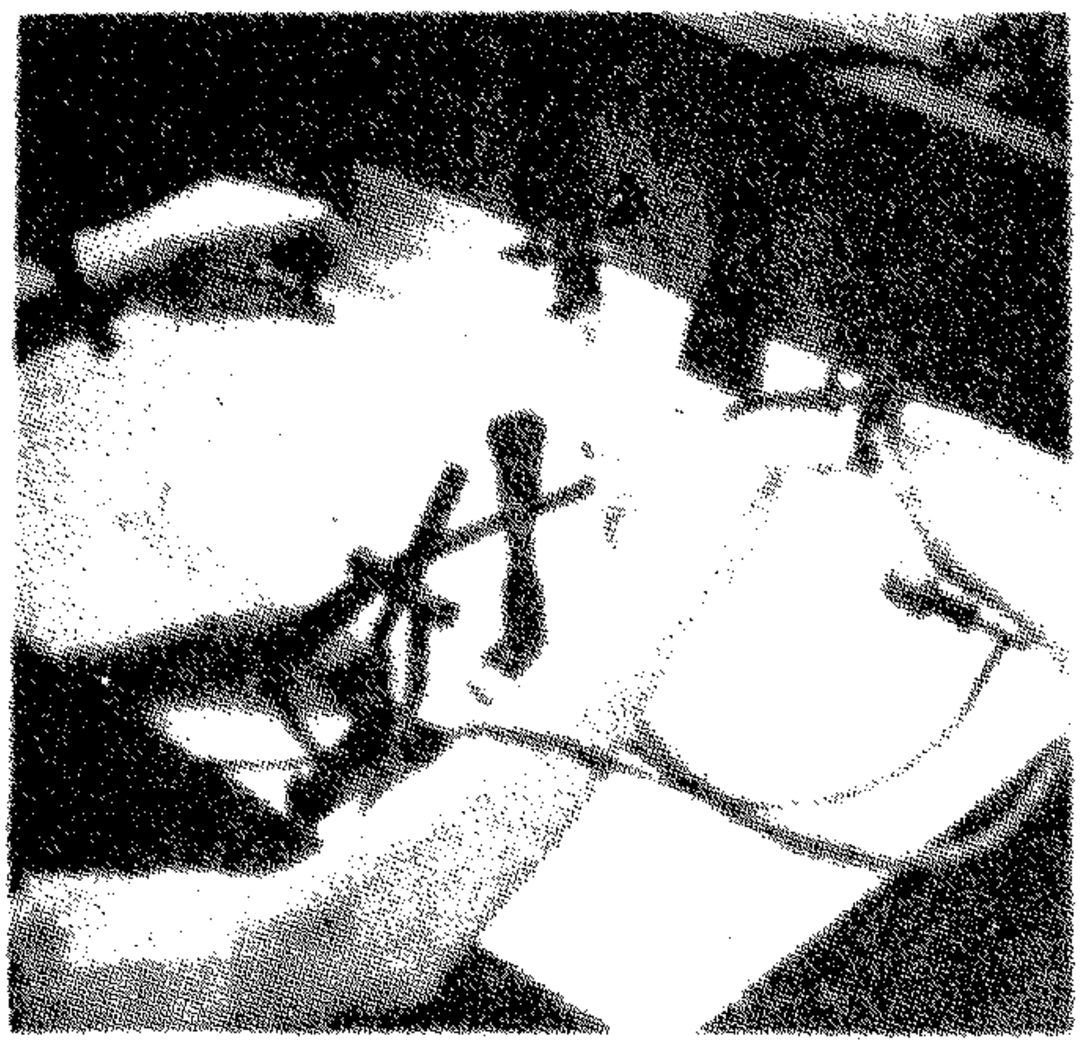

FIGURE 3

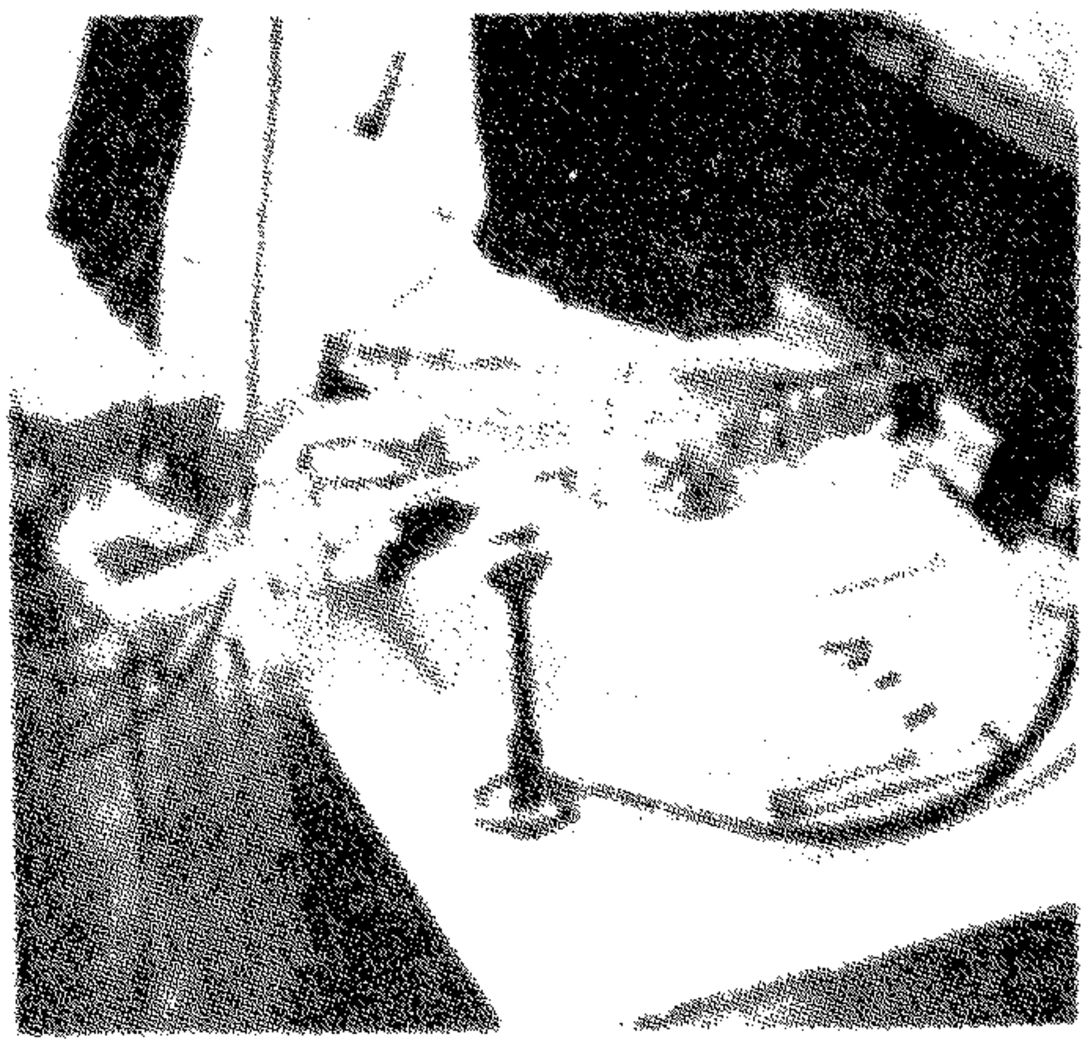

FIGURE 4

the shape shown in Plate III, Figure 1, A. Remove the tube from the flame and blow gently *with the cheeks* (not from the lungs) until about the stage shown at B in the Figure. Heat the bump until it has collapsed to about the condition shown at C and then blow it out as in D. Repeat this process all round the joint until all large and abrupt inequalities in thickness are gone and the joint looks something like Figure 1, E. It can be left thus in the shape of a small bulb or, for the sake of appearance, it can be heated all round and gently pulled apart until an approximately uniform diameter is reached, as at F.

The following difficulties will be encountered:

1. The ends of the tubes can not be rotated *and* held in line. There is no remedy but practice and attention to the way the glass is held.

2. The two ends, after being joined, can not be rotated at the same rate and as a result the hot middle part twists like a candy cane. Again, there is no cure but practice.

3. The joint cracks at the back while the front is being worked. This is due to working too slowly and to the glass not being hot enough. The beginner, beset by difficulties (1) and (2), finds it very comforting to let the back of the joint cool until it becomes fairly rigid, but unless he takes time now and then to warm the joint all round (and it must be hot enough to color the flame yellow immediately) the back will almost certainly crack. It may do so for either of two reasons. It may crack as a result of strains resulting from the hands being unsteady, or it may crack when heat is

eventually applied to it preparatory to blowing out the inequalities.

4. The joint develops pinholes. These are very annoying because they allow the air to escape and so prevent the joint being blown and also because a joint is not a joint if it has pinholes in it. They can arise in either of two ways. If the ends of the tubes were not jammed squarely enough or firmly enough together in the first place, openings may have been left. Or again, if in blowing out the bumps, too small a flame was used and the blowing was not under control, the hot spot may have been blown right out as in Plate V, Figure 1, B. If the holes are quite small and the glass around them is fairly thick, they will generally close if the flame is played directly on them. If this fails, the joint can be heated all round and, when very soft, pushed together until either the hole is closed or enough glass has accumulated to enable it to close when heated. Still another remedy, but one calling for somewhat more skill, is to fill the opening with glass melted in from a bit of glass rod about 1 mm in diameter. These rods are very useful for a number of purposes (mostly emergencies) and a supply of them should be kept on hand. They are made by heating a piece of tubing until it collapses completely, and then drawing out the hot bead of glass into a rod. The writer once used such a rod as the cylindrical lens in a Rayleigh refractometer.

5. When an attempt is made to blow out the inequalities, the thin parts of the glass tend to blow out altogether while the thicker parts remain unaltered. This difficulty is overcome by heating the work thor-

PLATE III

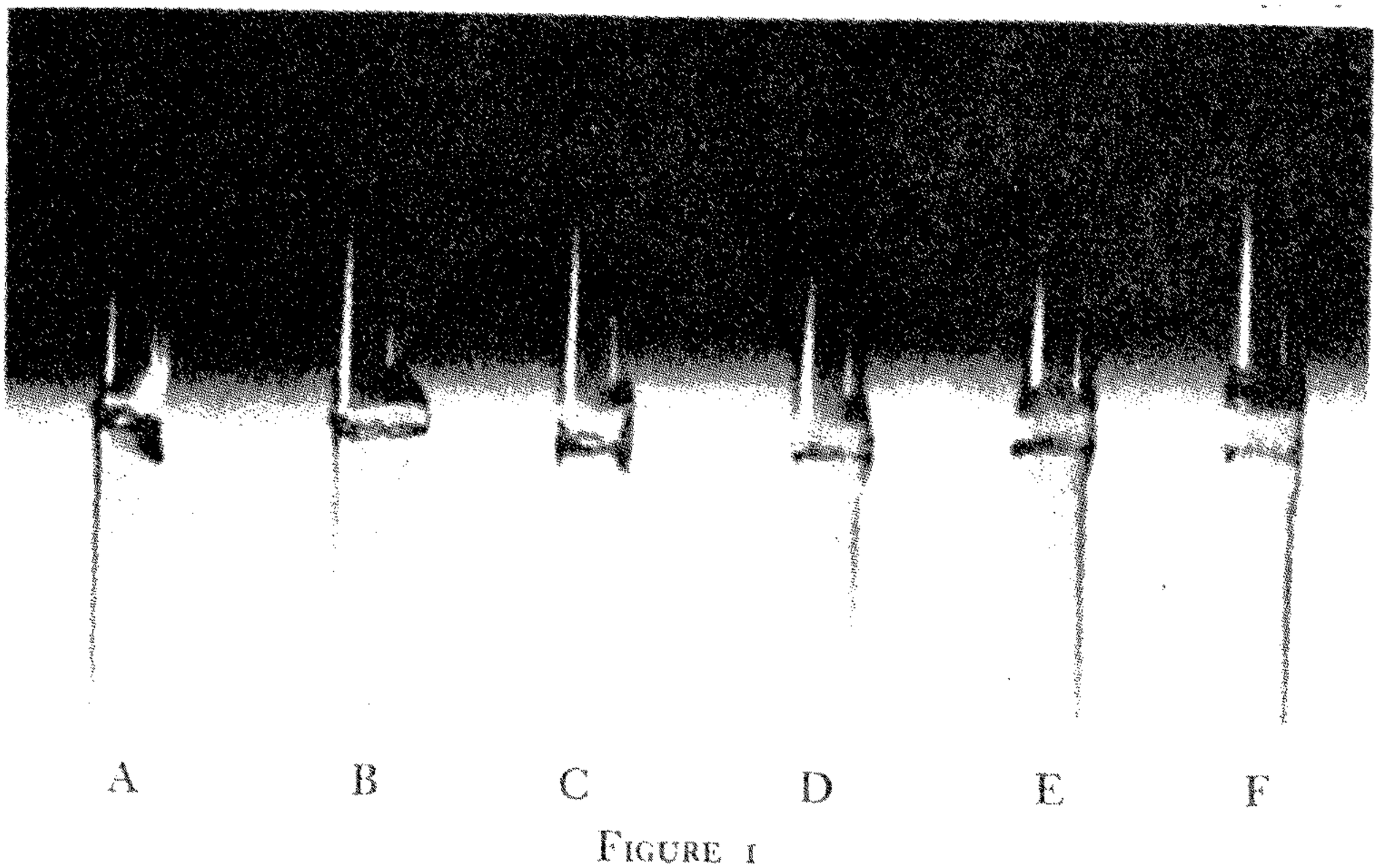

FIGURE 1

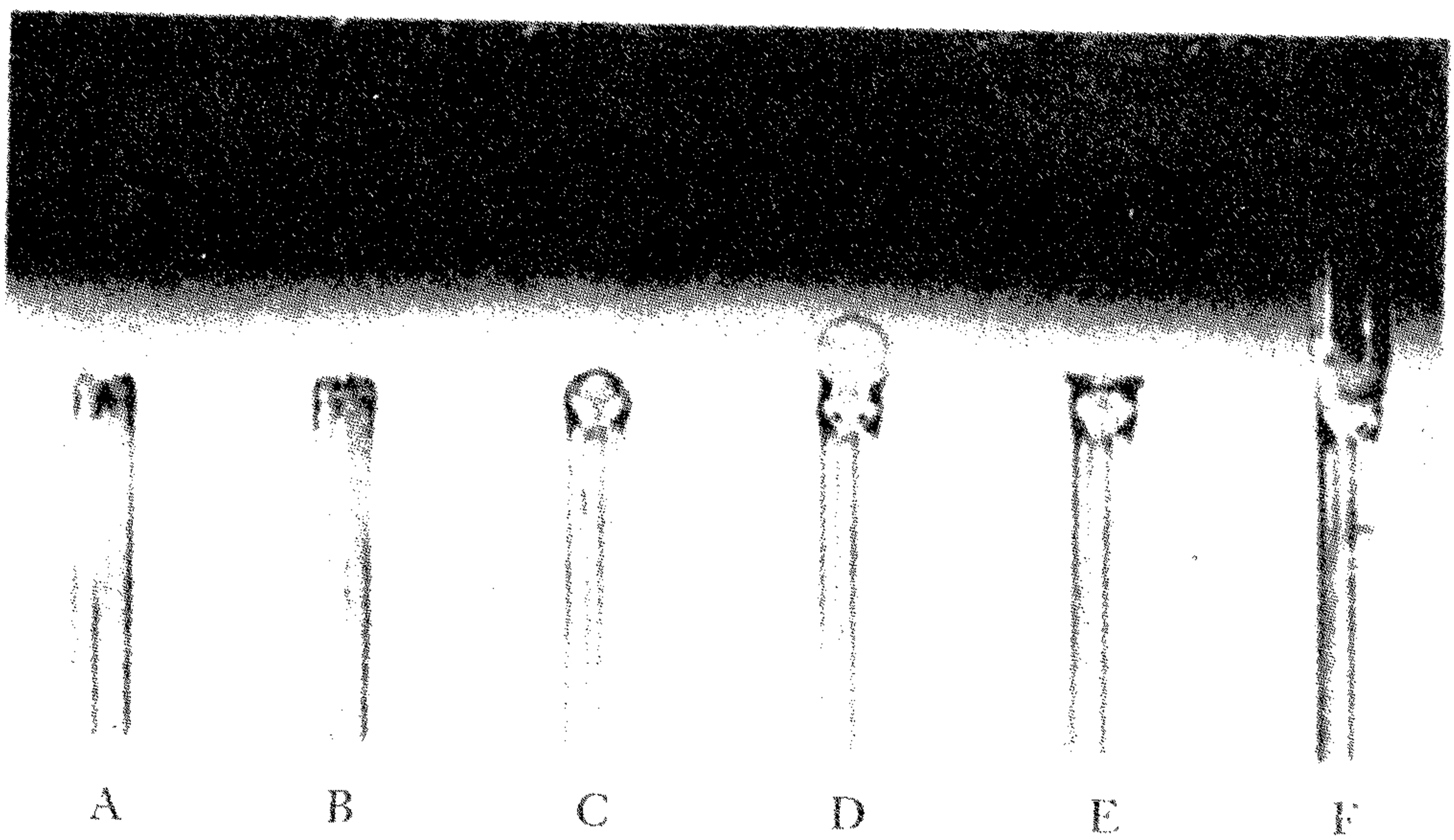

FIGURE 2

oughly, removing it from the flame, and waiting a second or two before blowing. If this is done, the thinner parts will have time to cool and stiffen while the thicker parts remain hot and plastic when the blowing takes place. After a time one comes to feel instinctively when to blow and how hard. It is a good idea to do the blowing in a series of tiny puffs (from the cheeks) so that the plasticity of the various parts of the joint can be judged.

Most of these difficulties can be overcome by practice and by remembering to get the glass hot and keep it hot. Failure to heat the glass sufficiently is the besetting sin of every beginner. Partly he fails to get the glass hot because it thereupon becomes too wobbly. Partly he fails because he uses too small or too soft a flame. And partly he fails because, in his eagerness to heat the glass, he brings it too close to the jet so that the blue inner cone of the flame (which has a core of cold unburnt gas) plays on the work and actually cools it.

II. *Joining Tubes of Unequal Size*

This resolves itself into two operations: (1) drawing down the larger tube until it is about the same size as the smaller one, and, (2) joining them. The second of these operations is no different from the one just described and needs no further discussion.

Drawing down the larger tube can be done in two ways and the choice between them is governed mainly by the size of the larger tube and the amount of draw-

ing down that is needed. When the larger tube is less than about 20 mm diameter and is to be drawn down to about 8 or 10 mm, the following method is easier.

Using a blast flame of the proper size, or, if the tube is too large, a blast flame in conjunction with a Meker burner as shown in Plate II, Figure 3, heat the tube all round. As soon as it softens, pull it apart *a very little bit* so that it develops a slight "waist." See Plate IV, Figure 1, A. Then, rotating the tube continuously and keeping the same sized flame, heat the waist strongly and with as little further pulling apart as possible, so that the walls collapse inward yet retain their thickness. When the collapsed part is a little wider at its narrowest part than the smaller tube, remove it from the flame and draw it apart a little (still rotating it) so as to obtain an approximately cylindrical part that is about the same diameter as the tube to be joined on. See Plate IV, Figure 1, B. Cut the tube at the drawn down part and seal on the smaller tube by the method already described, as at C in the figure.

When the larger tube is very large, 25 mm or more, or when it has to be attached to a tube of very small diameter, it will be found that while the tube can be drawn down in the way described to a certain extent, after a certain stage the collapsed part becomes paper thin. When this happens the second method, shown in Plate IV, Figure 2, is used.

Proceed as above until the glass begins to get very thin and then, using a large flame, pull the tube apart altogether so as to close it completely, as at A in the Figure. When the end is pulled off in this way it sometimes

described and needs no further discussion.

Drawing down the larger tube can be done in two ways and the choice between them is governed mainly by the size of the larger tube and the amount of draw-

ing down that is needed. When the larger tube is less than about 20 mm diameter and is to be drawn down

happens that a long taper is obtained with a sizable bead of glass at the end. As this is undesirable, the excess glass should be removed in the following way. A short length of glass is roughly fused to the end to serve as a handle and the tapered part is heated strongly and drawn out to a considerable distance so as to pull the excess glass out into a long string which can be cut off. The end is then melted to produce about the shape shown at A in Figure 2, Plate IV. Now direct the blast flame, supplemented if need be by a Meker, almost directly against the end of the tube, with continuous rotation, until it has collapsed to about the condition shown at B. Then take it out of the flame and, holding it closed end up to prevent distortion due to gravity, blow it out to the form shown at C. It may be necessary to repeat this melting in and blowing out a number of times before the end is well rounded. Now, using a small blast flame directed across the very tip of the closed end, heat the end and blow a little bulb on it as shown at D. Heat the end of the bulb till it collapses and then blow it out altogether or until it is very thin. Strike off the ragged bits of glass with the tail of a file, smooth the edge of the hole in the flame, and seal on the smaller tube as shown at E.

This method of drawing down calls for less manipulative skill than the first but it takes rather longer. It will be seen that it involves closing the end of the tube completely and then opening a hole of the correct size. The instructions given for closing and rounding the end of the tube are, of course, valid when it is desired to do just that.

III. *Opening a Closed Tube*

In the procedure given above, it was necessary to blow open a hole in the end of a closed tube. The same operation is called for in various other procedures (making T-tubes, sealing capillary tubes to larger pieces, etc.) and the following points are worth noting.

The size of the opening to be made is kept under control partly by adjusting the size of the flame and partly by controlled blowing. Thus, if the initial bulge is to small it can be melted in and a larger area of glass heated and a larger bulge blown. On the other hand, if the initial bulge is too large, it can be allowed to cool slightly and a smaller bulge blown on the end of it. In view of the possibility of such adjustments having to be made, the preliminary bulge should not be blown out too far—no farther in fact than is necessary to give an idea of its size. Once the preliminary bulge has been made, by repeatedly heating the end of it and blowing it out, most of the glass collects on the sides and the bulb eventually develops short but relatively thick and almost cylindrical walls, to which it is comparatively easy to attach the second piece.

IV. *Joining Capillary Tubing to Larger Sizes*

If the outside diameter of the larger tube is much greater than the outside diameter of the capillary tube, it will be necessary to draw it down by one of the methods described above.

The end of the capillary tube must be opened as well,

and this is done as follows. Heat the end of the capillary until it softens and the walls collapse so as to close the end completely. See, Plate III, Figure 2, A. Then direct the flame against the rounded end so as to heat it strongly, and blow a bulb. It may be necessary to heat and blow several times before getting a bulb of the right size, as shown at B and C. When a bulb like that at C has been obtained, heat the end of it and blow a thin bulb, as at D, strike off the thin glass, and smooth in the flame (E) and attach the larger tube as at D, this joint being made by the method of Plate III, Figure 1.

V. *T-Joints*

T-joints may be made with tubes of the same size or a small tube may be sealed to the side of a larger tube as, for instance, in attaching the water inlets to a condenser jacket. The procedure is essentially the same in each case, except that where a small side tube is being attached to a tube of larger diameter, special care must be taken to keep the larger tube hot all round in order to prevent it cracking at the back, and rather more thorough annealing is needed.

The cross-bar of the T, closed at one end and attached to the blowing tube at the other, is first heated all round until it begins to color the flame. The blast flame is then adjusted until its size corresponds with that of the tube to be sealed on, and it is concentrated at one spot. When the glass has softened there it is blown out gently so as to form a small bulge. See Plate V, Figure 1, A. The size of the bulge is adjusted by

melting it in and blowing it out until finally it is blown out altogether as at B in the figure, and the thin glass is struck off, after which the ragged edges of the hole are smoothed in the flame. If properly done, this will leave a hole about the same size as the tube which is to be sealed on. The side-tube, which has been cut to a convenient length and closed at one end, is now heated at its open end, the other part being kept hot as well, and then the flame is directed across the opening in the cross-piece and across the opening in the side-tube so that the edges of both openings become well softened. The side-tube is then stuck on firmly so as to avoid the possibility of pinholes, as at C in the figure. The joint is heated all round and then the flame is played directly into the angle between the two tubes. When the glass has melted in to about the condition shown at D in the figure, it is blown out as at E and then melted back to about the final shape. The process is repeated on the other side, and anywhere else that may be necessary, and the completed joint is annealed and cooled. See Plate V, Figure 1, F.

During this heating and blowing it will be necessary to support all three ends should they show a tendency to sag. See Plate V, Figures 2 and 3.

In making T-joints with capillary tubing, if the cross-piece is of large bore tubing and the side-tube of thick walled capillary, the joint is made by the above method, the capillary being first opened out at the end as shown in Plate III, Figure 2. If both parts of the T are to be of capillary tubing, the best plan is to enlarge the bore of the cross piece by heating it all round and

PLATE V

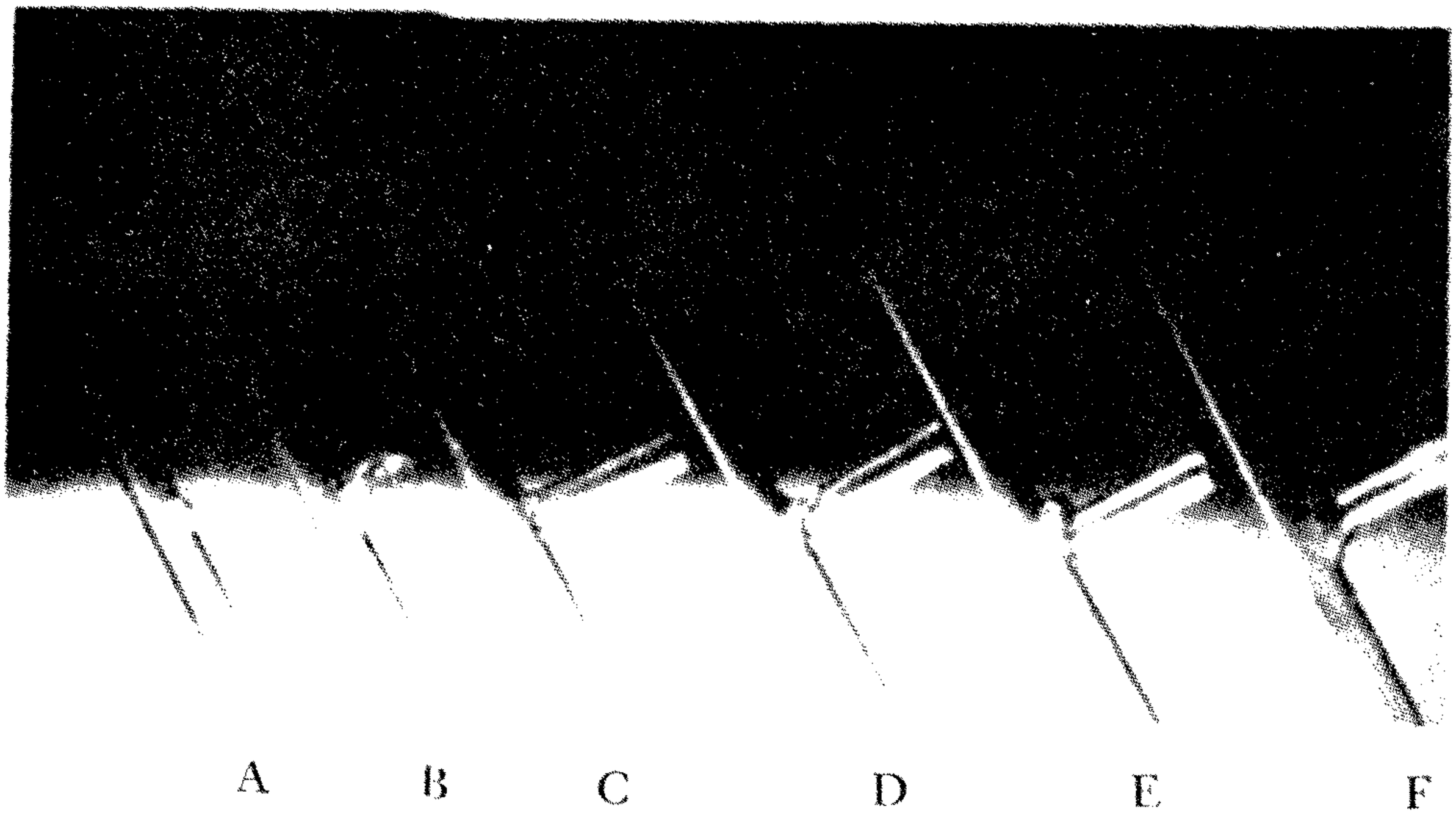

FIGURE 1

FIGURE 2

FIGURE 3

blowing a bubble in it. If, as the bubble is blown, the ends of the tube are drawn apart slightly, the outside diameter of the tube can be maintained practically constant. The T-joint can then be made in the way outlined above.

When the internal volume of the piece must be kept at an absolute minimum, it is possible to blow out only one side of the capillary cross-piece and seal on the capillary side-tube, but such a joint is difficult to make satisfactorily and is very likely to crack. The maker must decide whether the economy in volume is worth the risk of the joint "letting go" at an inopportune moment.

VI. *Bending Tubing*

The important thing in making bends is to keep the bore of the tube open at the bent part. Unless the bending is done properly the glass on the inside of the bend will flatten and the tube be constricted. This difficulty is due primarily to the glass being bent before it is fully softened, so the first rule in making bends is to heat the glass very thoroughly indeed and to heat it all round. With tubing of large size it is generally necessary to blow into the tube a little while it is being bent and the bending should be done quickly so that there will be plenty of time to make any final adjustments in the angle obtained. The ends of the tube should be bent upwards —U— rather than downwards —∩— for which reason the writer generally holds the tube as shown in Plate II, Figure 4 during the heating.

CHAPTER V

THE SPLICING TORCH

THE splicing torch is a most useful piece of equipment in laboratories where any considerable amount of apparatus has to be made. It consists of a straight, tubular handle through which a mixture of gas and air enters, welded at the top to a U-shaped tube each arm of which terminates in a burner outlet. These are arranged so as to direct a pair of flattened flames inward across the U so that a glass tube can be heated all round by rotating the torch through ninety degrees. See Plate VI, Figure 2. After a little practice, straight joints and T-joints can be made much more quickly with the splicing torch than with the blast lamp, and the result is considerably neater as can be seen from Plate VI, Figure 1.

An almost identical torch, known as a tipping torch, is used for sealing off evacuated apparatus (Neon tubes, radio tubes, etc.) at the pump, and it can be used also as a splicing torch. The tipping torch gives a somewhat smaller flame than the splicing torch and so cannot be used for splicing the larger tube sizes.

Both the tipping and the splicing torch require that

PLATE VI

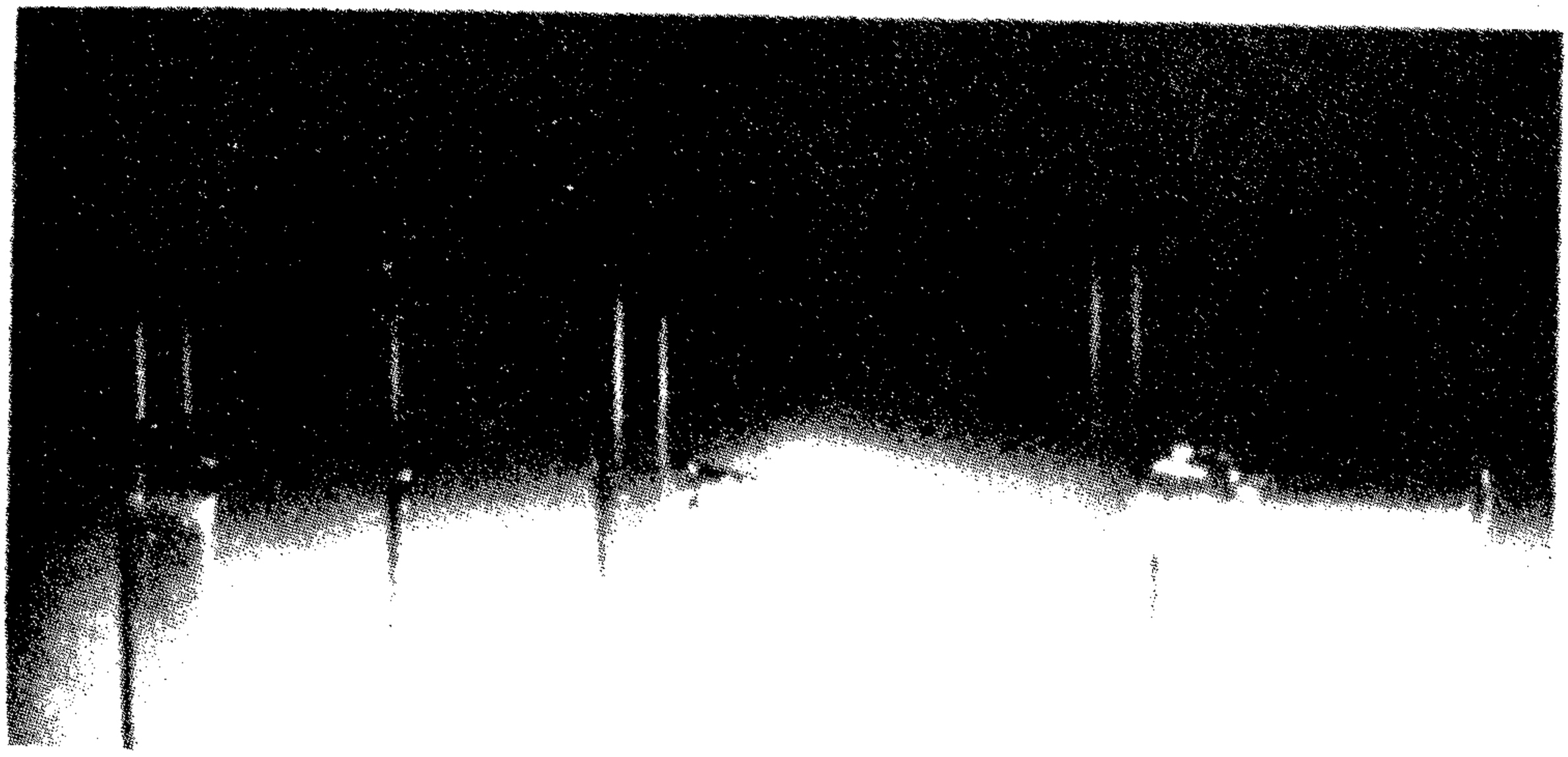

FIGURE 1

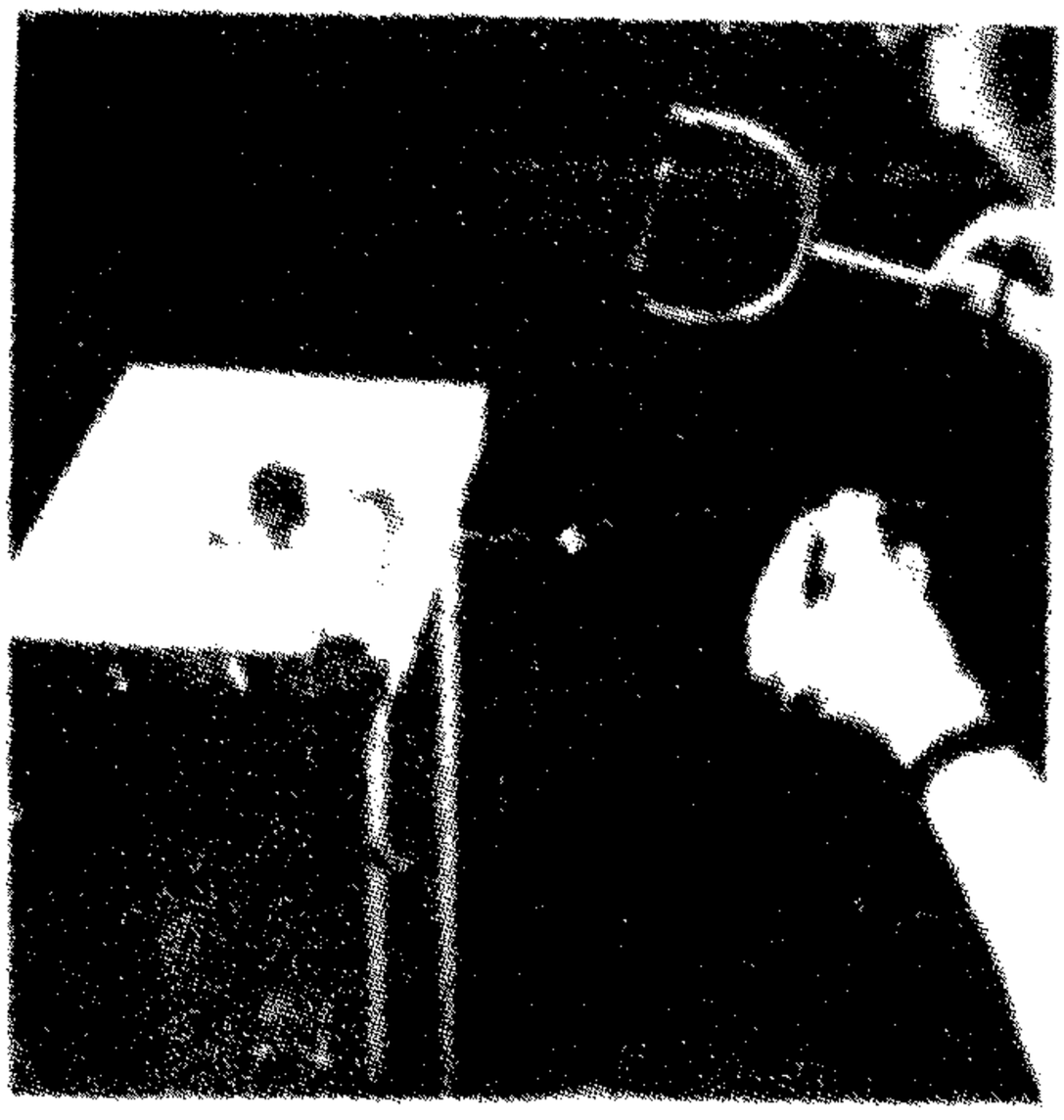

FIGURE 2

FIGURE 3

the gas be supplied at a rather higher pressure than is usual in the gas mains and a booster pump of some sort is required. (Suitable boosters are, the Rotary Blower, Catalogue No. 1–092, obtainable from the Fisher Scientific Co., or the No. 90105 Blower and Pump, obtainable from the Central Scientific Co.) A controlled amount of air must be mixed with the gas before it is supplied to the torch, and a valve such as the ones used at the base of an ordinary Bunsen burner is adequate if it is attached to the inlet side of the booster pump.

Figure 3, Plate VI shows the apparatus used by the writer. In order to make the outfit portable, the pump is mounted on a shelf below a small wooden table with an asbestos-covered top. Two screw pinch-clamps mounted on the side of the table enable the supply of gas to the pump and of air-gas mixture to the torch to be controlled independently, while the admission of air is adjusted by rotating the ring of the air inlet which happens to be built into the pump. A couple of hooks screwed to the side of the table hold the torch when it is not in use.

The flame must be adjusted by varying the air supply, the gas supply, and the rate with which the mixture reaches the torch, until the flame from each burner is free from yellow luminosity and the two flames meet half way across the U. After a little experience has been gained, it may be found desirable to enlarge or reduce the flame size slightly to meet any particular need. For example, in sealing off evacuated apparatus at the pump, a rather smaller pair of flames is desirable in order to reduce the danger of the glass being sucked in.

In order to make a splice with either the tipping torch or the splicing torch, one piece of tubing is stoppered at the end and supported so that the open end projects off the table. The other piece is attached to the blowing tube and held in the hand. The ends are brought close together and heated thoroughly. When well softened, they are pushed together and the heating continued, the thickened glass being blown out a little and allowed to collapse until all the abrupt changes in thickness have been eliminated all round the joint and it is marked by a single, moderately thick ring of hot glass. If the tubes are placed horizontally, it will probably be found that the ring is a little thicker at the bottom than at the top as a result of the effect of gravity. This condition is corrected during the next step. When the original inequalities have been eliminated, the flame is removed and the free end of the tube is lifted up and at the same time drawn away slightly, see Plate VI, Figure 2, and then, as the glass begins to cool it is allowed to drop slowly until the two halves of the tube are once more in line. The diameter of the tube is maintained during this process by blowing gently. This does away with the excess glass at the bottom of the joint. Clearly, if the tubes are placed vertically during the splicing, it is only necessary to draw them apart slightly after the original inequalities have been cleared away.

If the joint is not satisfactory after being drawn out, it can be re-heated, pushed together a little, and once more blown and drawn out.

T-joints with the splicing torch are equally easy to

make. The cross-bar of the T is supported on the table with its corked end projecting and the end attached to the blowing tube on the table. After being first heated all round at the desired place, it is heated strongly at one spot using a corner of one of the flames, and blown open exactly as in Plate V, Figure 1. The thin glass is brushed off with the side of the torch and the edges of the hole smoothed, and the side tube is sealed on in almost exactly the same way as was described above for a splice. See Plate VI, Figure 3.

The splicing torch is particularly useful in the construction of large or complex assemblies, such as are involved in high vacuum work or work with gases generally. In the writer's experience, at least three times as much work can be done in a given time with it than with the type of hand torch shown in Plate I, Figure 1. Its disadvantages are in the relatively higher cost of the torch itself, in the necessity of using a booster pump, and in the fact that the same torch can not be used with both air-gas and oxygen-gas mixtures, but where much apparatus has to be built, such a torch will be found invaluable.

CHAPTER VI

MORE ADVANCED OPERATIONS

I. *Bulbs*

BULBS may be blown either at the end of a tube or in the middle. The two operations are not fundamentally different and in each case the main problem is to obtain a bulb of adequate wall thickness and strength. Hence the first step is to accumulate a considerable amount of glass at one point and this is done as follows.

Using a rather small flame, heat the tube all round and when it is hot push it together while rotating it so as to obtain a thickened ring of glass as in Plate VII, Figure 1, A. This procedure is repeated a number of times to give a result like that shown at B. If the bulb is to be on the end of the tube, it is then sealed off as at C; otherwise the two ends of the tube are left on. Using a larger flame, the accumulated rings of glass are all heated with constant rotation until they melt together as at D, when they are blown out a little as at E. This is repeated if necessary to remove all traces of the rings and give a small bulb with uniformly thick walls.

PLATE VII

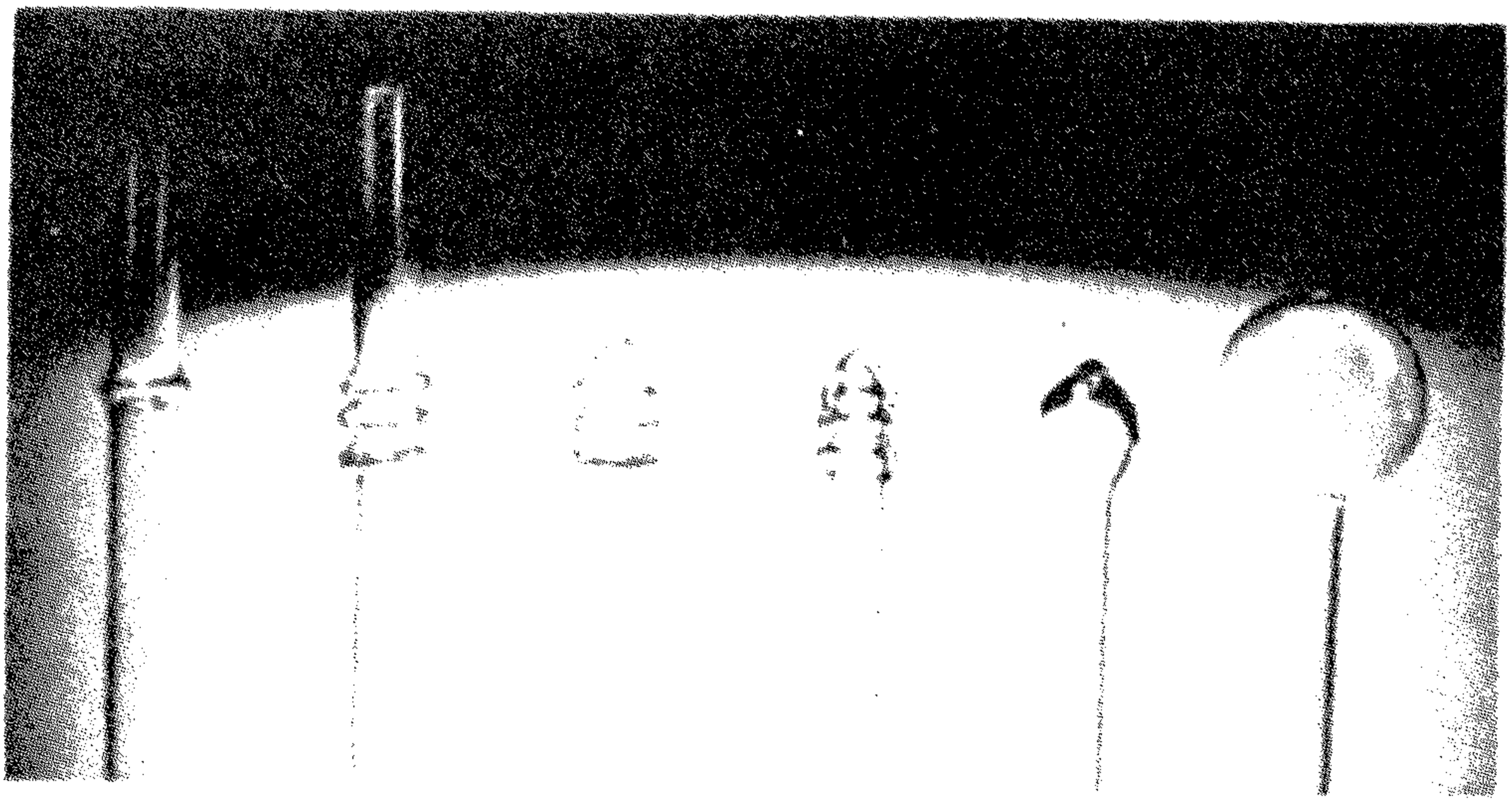

FIGURE 1

FIGURE 2

It is then heated strongly and the final bulb blown in one operation, using a series of rapid puffs and holding the tube vertically to prevent it distorting under gravity. Once blown out to the stage shown at F, it is practically impossible to re-heat and re-blow the bulb without distorting it hopelessly. If a very large bulb is required or if a bulb is to be blown in moderately small tubing, it will be impossible to collect enough glass by the method given above. Hence a piece of large diameter tube must be spliced into the smaller tube and the above procedure carried out on it. However, it will generally be more satisfactory to use a round-bottomed flask and seal on whatever outlet tubes are required, by the method shown in Plate IV, Figure 2, D and E.

Figure 2 in Plate VII shows the steps in making a small, thick-walled bulb of the kind used in determining vapor density by the method of Maass and Russel, (J. Am. Chem. Soc., *40*, 1565; 1918).

II. *Ring-, Triple- or Inner-seals*

These are required in making traps, mercury vapor pumps, and in various other connections. There are several methods, each having its own advantages and disadvantages, and the choice between them will depend on the size and purpose of the joint.

One of the easiest ways of making a triple-seal is to start by making a joint like that shown in Plate IV, Figure 1, C, or Figure 2, E, and, while it is still hot, drop into the larger tube a section of tube of the desired length and diameter. The outer tube is held large end

up so that the flared end of the piece inside rests against the inner surface of the tapered shoulder. The whole piece is rotated slowly in this position with the flame directed against the shoulder where the inside piece touches it, until the two have become thoroughly fused together all round. Then hold the piece horizontally and, still rotating and heating it, draw it apart slightly with gentle blowing so as to straighten it. The inner piece can be made to line up with the axis of the whole by warming the joint in a large flame with the piece held horizontally until the inner tube has sagged into position and thereafter rotating until the glass has become firm. The joint shown in Plate VIII, Figure 1, A was made in this way.

When a T-piece is required close to the triple seal it can either be put on first or immediately after making the triple joint and while it is still hot, because once cooled, it is generally difficult to re-heat a triple seal without cracking it.

Plate VIII, Figure 1, B shows a ring-seal made by an obvious variant of the above procedure.

The second method of making a triple-seal is as follows. Close the end of the larger tube as shown in Plate IV, Figure 2, C, and while it is still hot drop in the inner piece cut to the correct length but not necessarily flared. Hold the large tube closed end down and heat the end until the inner piece sticks to it. Quickly reduce the size of the flame and open the end of the tube by blowing a small bulb on it as was done in Figure 2, D, Plate IV. Then attach the smaller tube as before, line up the piece inside and anneal thor-

piece is rotated slowly in this position with the flame directed against the shoulder where the inside piece touches it, until the two have become thoroughly fused together all round. Then hold the piece horizontally and, still rotating and heating it, draw it apart slightly with gentle blowing so as to straighten it. The inner piece can be made to line up with the axis of the whole by warming the joint in a large flame with the piece held horizontally until the inner tube has sagged into position and thereafter rotating until the glass has become firm. The joint shown in Plate VIII, Figure 1, A was made in this way.

When a T-piece is required close to the triple seal it can either be put on first or immediately after making the triple joint and while it is still hot, because once cooled, it is generally difficult to re-heat a triple seal without cracking it.

Plate VIII, Figure 1, B shows a ring-seal made by an obvious variant of the above procedure.

The second method of making a triple-seal is as follows. Close the end of the larger tube as shown in

oughly. This gives a joint like that shown in Plate VIII, Figure 1, C.

Joints like the one shown at D in Plate VIII, Figure 1 are sometimes required and are made by a variant of the foregoing method. The inner tube is first flared slightly, bent, and cut to size. The outer tube is heated all round at the right place and the flame then concentrated and a small bulge blown. This bulge should not be blown out too far, but its diameter should be large enough for the end of the inner piece to fit into it. While the glass is still hot, the inner tube, also hot at the end, is dropped in and shaken and tapped until it lies with its flared end (or one side of it) touching the proper part of the bulge and the flame is concentrated until the inner piece sticks at one spot. The whole piece is then held in such a position that the inner tube, pivoting on the hot point of attachment, falls into a position such that the outer tube can be heated and made to collapse (helped, perhaps, by gentle suction) so that it sticks to the opening in the inner tube all round. The diameter of the outer tube is then restored by heating and blowing gently, and finally the outer T-piece is put on by a process intermediate between that shown in Plate IV, Figure 2 and Plate V, Figure 1. It is then bent to shape and the whole joint thoroughly annealed.

II. *Flaring the End of a Tube*

There are several methods of flaring the end of a tube. With small sizes, 10 mm or less, the end is heated for a distance of about 10 mm, the tang of a file is thrust

in to a depth of about 2 cm, the tip of the file placed against the inner wall of the tube, and the end flared by rotating the tube and gradually pushing the softened glass outwards with the side of the file. The whole operation must be done quickly, while the glass is hot, but at the same time the glass must not be pushed too far all at once lest it wrap itself round the file. It may be necessary to do the flaring in stages.

With larger tubing, the same method can be used if a carbon rod (such as is used in arc lamps) takes the place of the file, but difficulty will be found in rotating the larger tube steadily with the fingers of one hand. The following method is more satisfactory.

Heat the end of the tube all round for a distance of about 2 cm until it is very soft. Quickly lay it on the edge of the table with the hot end projecting, and roll the tube back and forth with the palm of the left hand. The carbon rod held in the right hand, is thrust into the end of the tube and made to press the glass into the desired form. See Plate VIII, Figure 2.

A more elaborate way of flaring the end of a tube is described later in connection with the making of ground joints.

III. *Condensers*

A condenser like that shown in Plate IX, Figure 2, A, has a triple seal at each end. It is made as follows.

The triple seal at one end is made by one of the methods described above and shown in Plate VIII, Figure 1, and the side tube through which the water

PLATE IX

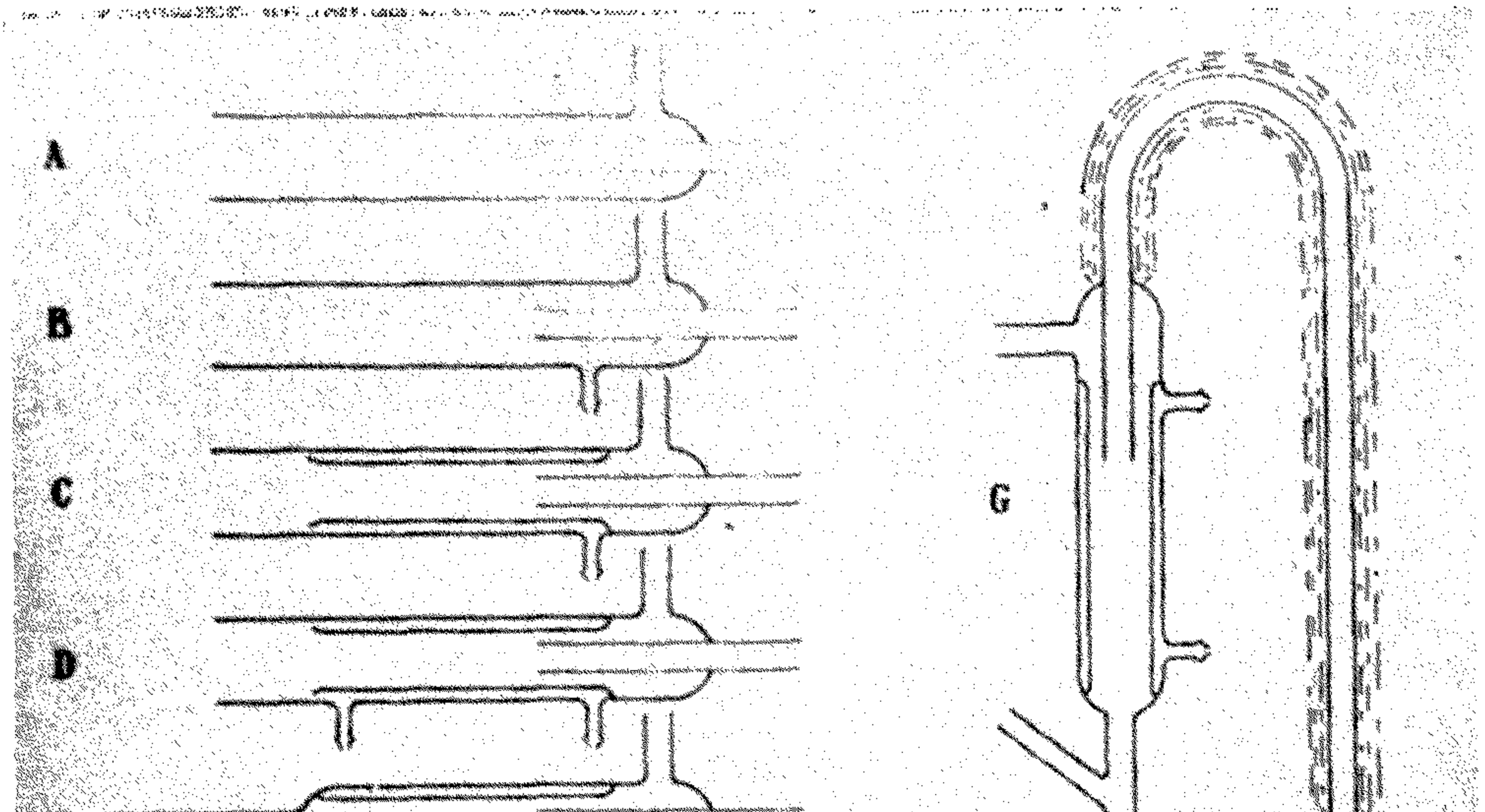

FIGURE 1

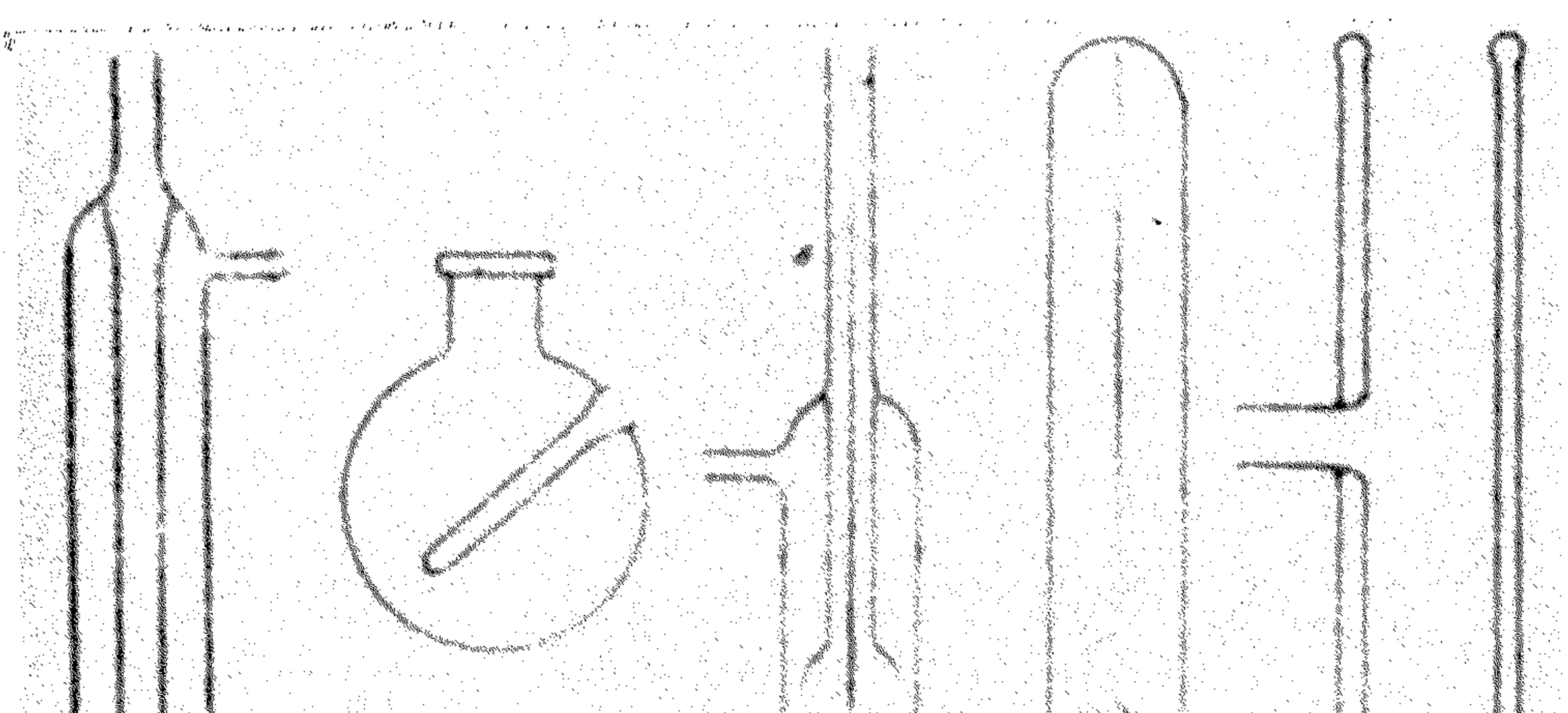

FIGURE 2

enters is sealed on. The joint is then annealed and cooled. Before sealing it in place, the inner tube has been cut to the correct length and flared at the other end. The outer tube over the flared part can be drawn down as shown in Plate IV, Figure 1 until it becomes fused to the edges of the flared end and then cut off a little way past the seal and the condenser outlet tube and water inlet put on. Note that as soon as the outer tube has been sealed to the inner tube at both ends there is no communication between the inner tube and the water jacket so that the blowing tube will have to be moved when the water inlet is added. The ring of glass at the tip of the water inlet and outlet is made as shown in Plate VII, Figure 1, A, and should be completed before they are attached to the jacket.

The procedure in closing the lower end of a condenser is illustrated in Plate IX, Figure 1 in connection with the making of a mercury vapor pump.

IV. *Thermometer Wells*

Figure 2, B, Plate IX shows a flask used in conjunction with a fractionating column and containing a thermometer well. The problem in making such a well is complicated by the fact that the well is closed at the bottom and hence, after it is sealed onto the inside of the flask, the circle of glass covering the outer end can not be blown away as was done in making the joints shown in Plate VIII, Figure 1, C and D.

The inner tube is attached to the wall of the flask in the same way as was the inner piece of the joint

shown in Plate VIII, Figure 1, D. In order, then, to open the entrance to the well, the circle of glass covering the end of the well is heated strongly and touched with a bit of glass rod which is immediately pulled away as far as possible. This draws out the circle of glass into a long, tapering tube which is then cut off close to the bulb, smoothed in the flame, and opened if need be with the end of a file.

V. *Glass Diaphragm Manometers*

It is sometimes necessary to measure the pressure in a system that is completely glass enclosed. For this purpose a pressure indicator that depends on the flexibility of a thin glass diaphragm or loop of tubing is required. The unknown internal pressure is matched by a known external pressure and the flexible indicator is used to show when the two are equal. A large number of such devices have been described in the literature, and the construction of two will be described here.

Figure 2, C, Plate IX shows a diaphragm manometer. The steps in making it are as follows. The inner tube, which should be about 10 mm in diameter, is triple-sealed into the larger outer tube which is then cut off a few centimeters from the triple seal so that the inner tube projects far enough for the diaphragm to be blown on the end of it. This is accomplished by closing off the end of the inner tube by the method shown in Plate IV, Figure 2, and it is then heated and blown out into a thin bulb. Several trials will probably be re-

quired before a bulb that is thin enough but not too thin is obtained. It will not be necessary to collect extra glass for the bulb by the method shown in Plate VII. Having obtained a satisfactory bulb, the bottom of it is melted in a little way, using a tiny flame about 7 mm long, obtained by using a jet made by drawing down the end of a glass tube.

The end of the bulb should not be flattened too far. Examination of the figure will show that the angle between the diaphragm and the curved side of the bulb is highly obtuse. If the bulb is flattened too much this angle becomes acute, and the diaphragm is very easily broken by a comparatively small pressure difference. A diaphragm of the shape shown, will easily withstand a vacuum on its inner face and at the same time be thin enough to respond to a pressure difference of half a millimeter.

After the diaphragm has been made and tested for strength by evacuating the inner side and for flexibility by seeing whether it will bend in response to moderate blowing, a long pointer is sealed onto its inner side. The pointer is made by drawing out a glass tube or rod to a length of about 20 cm and a maximum diameter of 1 mm. One end is drawn out to a fine tip and blackened with india ink. The pointer is dropped down into the inner tube and its larger end sealed to the center of the diaphragm using the pin-point flame. The reference point, similarly blackened, is then attached to the inner side of the tube at the top and its tip brought in line with the tip of the pointer.

The outer tube which was cut off to permit the dia-

phragm to be made is now sealed back on with a hand torch and the instrument is complete.

In use, the inner tube is filled with some liquid which will surround the pointer and keep it from vibrating, and the movements of the pointer are magnified by means of a lamp and projection-lens which throw an enlarged image of the pointer and reference point on a scale some distance away.

The instrument has the following advantages. The end of the pointer is some centimeters above that part of the apparatus which contains the gas whose pressure is to be measured. This enables it to be well immersed in a thermostat. The shape of the diaphragm chamber makes it easy to determine the volume of the gas whose pressure is being measured. The projected image of the pointer can be seen from all directions and so there is less danger of an excessive pressure difference breaking the diaphragm. The displacement of the pointer from its null position with zero pressure difference is practically proportional to the pressure difference which produces it, so that the external pressure needs only to be made approximately equal to the unknown internal pressure, after which a small correction depending on the displacement of the pointer and the constants of the instrument is added or subtracted. This makes it possible to make readings quickly. Accidental displacements of the projection lens, etc., can be made good without affecting the calibration or the null point. (Other methods of magnifying the movement of the pointer optically do not have this advantage.) Finally, the instrument has no temperature coefficient.

Plate IX, Figure 2, D, shows another type of instrument having the same advantages as the above, except the first two, and which is somewhat easier to make.

A moderately thin bulb of 1 to 2 cm diameter is blown in a tube which is drawn out to a long point on one side of the bulb. The bulb itself is then heated on one side and by judicious sucking drawn into the shape shown. If the bulb was sufficiently thin, the tip of the drawn out pointer will waggle back and forth several millimeters when air is blown into or sucked out of the tube. It is then ring sealed into a larger tube by the method used in Plate VIII, Figure 1, A, and a reference pointer attached. The movements of the pointer are magnified as before, but as the pointer can be made shorter and thicker it is not usually necessary to fill the outer tube with liquid to prevent it vibrating. Instruments of this type can probably be made a little more sensitive than the one described before.

VI. *Vacuum Jackets*

Plate IX, Figure 2, E, shows a vacuum jacketed vessel used in a calorimeter. The re-entrant joint at the end is made by a variant of the method used in producing the ring-seal shown at B in Figure 1, Plate VIII. The inner tube is flared at its open end until it fits closely into the outer tube and is then supported so that the flared lip comes just at the open end of the outer tube. The two are then sealed together with a hand torch, using a thin glass rod to close any pinholes that may develop. The joint should be carefully annealed. When

it is cool, the outer tube is drawn down at the opposite end and a small tubulature attached through which the jacket can be evacuated.

The side-tube passing through the vacuum jacket was intended to admit a thermometer to the interior and is a rather unusual requirement. When required, it can be produced by either of two methods.

If it has to be put on after the re-entrant joint has been made, the outer tube is heated all round and then very strongly at one spot and by sucking through the tubulature at the bottom the outer tube is drawn in until it sticks to the inner tube. The double thickness of glass is then blown out as in Plate V, Figure 1 and the side-tube attached as before. It is, of course, necessary to blow from the re-entrant end to do this. The vessel requires very careful annealing indeed.

A considerably neater result can be achieved if the following procedure is used. Before making the re-entrant seal at the end, an opening with projecting lips is made in the side of the inner tube as shown in Plate V, Figure 1, B. In order to permit the re-entrant joint to be blown, the inner tube must then be plugged with a cork close to the opening in its side and far enough from the end for the cork not to be scorched by the heat. When the re-entrant seal has been completed and annealed, the cork is removed from the inner tube and the outer tube heated all round and then made to collapse onto the projecting lips of the hole in the inner tube. When it is well sealed onto them, it is opened by blowing into the re-entrant end and the side tube sealed on in the usual way. It may be necessary to arrange

the blowing tube so that the vacuum jacket and the interior of the vessel can be blown simultaneously—which can be accomplished by putting a T-tube in the blowing tube. Very careful annealing is required.

VII. *Closed Circuits of Tubing*

In making manometers, McLeod gauges, flowmeters, and other pieces of apparatus, a closed loop of tubing like that shown in Plate X, Figure 1 (right) may be required. The methods of making such closed circuits that are usually recommended require that the piece be softened at two points simultaneously—an operation calling for a good deal of dexterity. The method suggested in the figure avoids this difficulty. The two side tubes are sealed to the main tube and bent until their ends are properly aligned. The intervening tube which is to bridge the gap is cut to the correct length and held in place at one end by a short section of rubber tubing or by winding it with insulating tape, which serves also to seal the gap while the other end is being blown. A bit of thin rod will be needed to close the inevitable pinholes during this process. When one end is sealed, the rubber is cut away and the second seal made, a thin rod being used as before to fill in any gap that may have been left.

VIII. *A Mercury Vapor Pump*

Mercury vapor pumps of the Langmuir type have been made in a wide variety of forms, and the one

shown here has no particular advantage over some of the others. A description of its making is included only because it shows how necessary it is to plan the work and carry out the various steps in such a way that each joint will not have to be re-heated once it has been annealed and cooled.

The steps are shown in Plate IX, Figure 1, from which it will be seen that all the joints are of types that have been described in the foregoing pages.

A triple seal, made by the method of Plate VIII, Figure 1, C is first of all made. The inner piece should be cut to the proper length before it is sealed in place, and its lower end is better if it is ground square with carborundum powder and glycerine on a glass plate. While the joint is still hot, the side tube is attached as shown at A in Figure 1, Plate IX. The whole joint is then heated uniformly and, without delay, the water inlet is attached as at B. This tube should be ready beforehand. The bulge near its end, which keeps the rubber tube from slipping off is made as shown in Plate VII, Figure 1, A. The whole piece is heated uniformly in a large flame and the inside of the water jacket (which has been shaped previously), is sealed in position as shown at C in the figure. See also Plate VIII, Figure 1, B. The whole thing is now thoroughly annealed and cooled.

The annular gap between the mercury vapor jet and the inside of the water jacket should be from 1 to 2 mm wide. Its width will depend on the effectiveness of the backing pump to be used: with a poor fore-vacuum the gap must be narrow and the rate of pump-

ing somewhat slower (though just as effective), while with a good fore-vacuum the gap can be wider and the pumping faster.

The lower water inlet is next sealed in place as shown at D, and the bottom of the condenser drawn down and sealed to the inner tube as shown at E. This is the same operation as is required in producing the condenser shown at A in Figure 2, Plate IX. Once more, careful annealing is in order.

The connection to the backing pump shown at F is attached in the ordinary way and then bent upward as shown in order that condensed mercury will not splash over into the low-vacuum line.

The completed pump is shown at G. The mercury boiler is made from a 100 or 200 ml round bottom flask, and the closed circuit of tubing that is required in attaching the boiler and vapor delivery tube to the rest of the pump is made in the way described above. The asbestos lagging is put on last, preferably after the pump has been tested for leaks with a high frequency discharge coil or by some other method.

IX. *A McLeod Gauge*

A McLeod gauge, used for measuring low gas pressures, like that shown in Plate X, Figure 1 (left) is made as follows.

First select a capillary tube of about 0.5 mm bore and determine the volume per unit length of the bore. This is most conveniently done by partly filling the capillary with a thread of mercury, measuring the length of the

now made from a piece of 20–30 mm tubing. The length should be sufficient to give the bulb a volume of 75–100 cubic centimeters. The larger tube connected at C should be sealed on first, and then the capillary, A, which has already been got ready. (See Plate IV, Figure 1 and Plate III, Figure 2.) The T-piece at C is attached as shown in Plate V, and bent upwards while the T-joint is still hot.

The closed circuit containing the capillary tube, D, is now made up as described in Section 7 above. The purpose of the capillary tube at D is to compensate for the capillary depression of the mercury in A, for which reason it should have the same diameter as A, and may very well be cut from the same piece of stock. Before attaching this part, at E, the volume of the bulb, B, down to the side tube at C should be found by filling it with distilled water and weighing.

The completed gauge should be provided with a paper scale. There are two methods of using a McLeod gauge and scales may be provided to suit either or both of them.

First Method. In this method, the mercury reservoir is raised until the mercury rises in B and up into the capillary, A, to a mark made somewhere near the bottom of it. The pressure is then determined by observing how much higher the mercury stands in D than in A. To construct a scale to be attached to the tube, D, we note that if "a" is the volume of A down to the mark, and if "b" is the volume of A plus B down to the side tube C, then the gas which was originally at a low pressure in B has been compressed in the ratio b/a and its

pressure has been raised in this ratio (Boyle's Law). Hence, if the mercury in D stands at a height "y" cm above the mark on A, the value, "x" of the low pressure which it is desired to measure is,

$$x = \frac{a}{b} y$$

By assigning a series of values to "x" (10^{-1}, 10^{-2}, cm, etc.) and using the known values of "a" and "b," a series of values of "y" are obtained which can be marked off on a strip of paper which is then mounted on D with its lower end opposite the fixed mark on A.

Second Method. In this method, the mercury reservoir is raised until the mercury in D stands opposite the top of the bore of A. The position of the mercury in A is then observed. Suppose it stands at a distance of "y" cm below the top. The volume of the compressed gas is then Ky cubic centimeters, where K is the volume of A per centimeter of length. This gas has been compressed in the ratio b/Ky where "b" is, as before, the volume of A plus B down to C. Moreover, the pressure of the compressed gas is "y" cm so that the unknown low pressure is,

$$x = \frac{Ky}{b} y = \frac{Ky^2}{b}$$

As before, values of "y" are calculated for various assigned values of "x," and these are then marked off on a paper scale which is attached to A with its top level with the sealed end of the bore.

In both these methods the low pressure of the gas on the mercury in D is neglected.

Plate X, Figure 1 (center) shows an alternative way of attaching the side tube C to the bottom of the bulb, B. This has the advantage of making the volume of low pressure gas isolated in B by the rising mercury somewhat more definite and reproducible. For most ordinary purposes it is an unnecessary elaboration.

If the mercury is raised and lowered in the gauge by means of a levelling cup connected by a rubber tube to the lower end of the tube, C, it will be well to carry tube, C, down to a distance of at least 30 inches so as to minimize the possibility of leakage at the glass-to-rubber joint.

X. *Working to Fixed Dimensions*

It is sometimes necessary to make apparatus to meet more or less strict specifications as to size and shape, as, for example, in carrying out some of the A.S.T.M. Standard Tests. The procedure followed in making Neon tubes for advertising signs is particularly useful then. If the apparatus is drawn full size on sheets of asbestos, these can be laid out on the work table and the various parts cut out and bent to shape and spliced together right on the pattern. There is surprisingly little difficulty in meeting the strictest specifications by this method, particularly if a splicing torch like that described in Chapter 5 is used.

XI. *Assembling a Complex Apparatus*

In setting up a vacuum apparatus, or any other complex outfit involving a number of separate parts sealed together with glass connecting tubes, it is advisable to arrange a firm supporting frame. The "Flexaframe" outfits obtainable from the Fisher Scientific Company are excellent for this purpose. A somewhat cheaper substitute can be constructed by arranging a series of ⅜ or ½ inch vertical iron rods or pipes set six inches apart in a wooden frame six or seven feet high. The frame can be as long as necessary. The rods should extend to the floor and should be set in holes in the top of the frame with a washer and nut on each side of the wood so that the rods are clamped tight and will not twist.

With such a frame the apparatus can be supported firmly using ordinary apparatus clamps, and manometers, etc., can be set at a level most convenient for reading them—something that can not usually be done if the apparatus is built on a table. The frame should, if possible, be accessible from both sides and should be close to the water, gas and electrical services of the laboratory.

A still cheaper method, which is particularly suitable for relatively compact outfits, is to support the apparatus about four inches out from a wooden wall or large board by means of metal brackets. These can be cut from strips of heavy gauge galvanized iron about ¾ inch wide by 12 inches long. They should be shaped like a flat-topped A (without the cross-bar) and should

be screwed to the wall. The flat top should have a semi-circular depression in which the glass is held by a second strip of metal held in place by screws. These can be short wood screws driven into slightly smaller holes drilled in the bracket, but better results will be obtained if the bracket is drilled and tapped so that the clamping strip can be held in place with machine screws.

A splicing torch is invaluable in building such apparatus.

In every complex assembly, the problem of locating leaks sooner or later presents itself. If the apparatus is constructed entirely of glass the detection of leaks is generally comparatively easy, but if there are metal parts the difficulties are considerably increased.

The most convenient leak-locater is a high-frequency coil (such as the "vacuum tester," Cat. No. 1–179, of the Fisher Scientific Co.). When the pressure inside the apparatus is reduced to a few millimeters of mercury and the tip of the coil is brought near the apparatus, a violet glow is observed in the rarefied gas. When the tip of the coil is moved about over a suspected part of the apparatus, the site of a leak will be shown by a bright, white star of light in the glass.

If a high-frequency coil is not available, an ordinary spark coil can be used. One of the high tension terminals is connected to a length of well-insulated wire (which may, if desired, be attached to a glass handle) and the end of this wire is moved about over the surface of the glass. As before, leaks reveal themselves by a bright discharge passing through them into the evacu-

ated interior. The second high tension terminal may be grounded to the frame supporting the apparatus.

The electrical method will not reveal a leaking stopcock and it can not be used for finding leaks in or close to metal parts.

A small dentists' mouth-mirror is a very handy gadget for examining the backs of stopcocks, joints, and other inaccessible parts of the apparatus.

Sometimes it is uncertain whether a slow rise in pressure in an evacuated system is the result of a leak or due to the liberation of water or other vapor from the glass or stopcock grease, and much time can be saved if this uncertainty is cleared up promptly. The easiest way to do this is by an examination of the spectrum of the intruding gas.

For this purpose, a small, H-shaped discharge tube is attached to the apparatus. The cross-bar of the H is made of capillary tubing and each leg of the H carries an electrode. The tube is operated from an induction coil and the light from the capillary is viewed end on and analyzed with a small direct-vision spectroscope.

If the rise in pressure is due to a leak, the easily recognized spectrum of nitrogen will be observed. Its most striking feature is a large number of closely spaced lines in the red and orange part of the spectrum. If the gas is derived from the walls or the grease, these lines will be faint or absent altogether and instead there will probably be only a single strong line in the red part of the spectrum, this line being due to hydrogen derived from water vapor. In addition to this red line, there will be a number of others in the green, blue and violet,

due mostly to hydrogen and mercury vapor, but the total number and appearance of the lines is distinctly different from those observed in the presence of air. A large number of broad, fairly evenly spaced bands, if present, is due to carbon monoxide and generally indicates the presence of some organic vapor, usually derived from the tap grease.

The discharge tube is also useful in locating leaks in or near metal parts of the apparatus. It is sufficient to evacuate the system as completely as possible, start the discharge, and then paint the suspected parts with ether or some other volatile liquid. The appearance of the discharge will change suddenly when the liquid enters through a leak and evaporates.

CHAPTER VII

SOME SPECIAL OPERATIONS

I. *Sealing in Wires*

IN MAKING conductivity cells, discharge tubes, elec-trode vessels, and other pieces of apparatus, it may be necessary to seal a wire through the glass. The two physical requirements for a gas-tight seal are that the glass should wet the metal (which must therefore be free from oxide) and that the metal must have nearly the same coefficient of expansion as the glass so that the seal can be cooled without developing strains serious enough to make it crack.

Fine platinum wire can be sealed into lime-soda glass, but thicker platinum is hard to seal successfully. Hence it is better to interpose a little bead of lead-glass or special "sealing-in glass" between the platinum and the soda glass. In the manufacture of electric lamps, radio tubes, etc., where platinum would be too expensive, a special wire is used which has a core of an alloy with an expansion coefficient less than that of glass, covered with a sheath of copper whose coefficient of expansion is greater than that of glass. The thickness of the alloy core and the copper coating is made such that the wire

as a whole expands at practically the same rate as lead-glass.

Borosilicate glass expands much less than platinum so that it is difficult to seal platinum wire into it successfully. However, if the platinum is in the form of very thin foil, it can be done well enough for electrode vessels, though the joint may prove unreliable in high vacuum work. Where the joint must be completely gas-tight, tungsten wire is used with "Pyrex" brand of borosilicate tubing. The oxide layer is removed from the tungsten by heating it and rubbing the wire with a crystal of potassium nitrite (KNO_2). Since tungsten can not be soldered, the attachment of connecting wires to the tungsten may present some difficulty if a constant electrical resistance is necessary. A method of solving this is to copper-plate the ends of the tungsten to a depth of about 1 mm and then weld or solder the connecting wires to this deposit. See Wright and Marshall, Trans. Am. Electrochem. Soc., 149, 1928.

There is no metal which can be sealed directly into fused quartz.

Aside from the foregoing special points, the procedure followed in making glass-to-metal seals is practically the same for all types of glass. The wire to be sealed in is cleaned and a bead of glass about 2 mm in diameter is melted round it. With platinum this is done by sticking the wire lightly to the softened end of a glass rod or tube which serves as a handle, and then building up the bead by melting it on to the middle of the wire from a thin rod of "sealing-in glass." With tungsten it is necessary to prevent the cleaned metal

surface from being re-oxidized by the heat and the bead is therefore made as follows. A short length of thick-walled tubing is slipped over the cleaned wire and heated as rapidly as possible so that it collapses on the metal without delay, forming the necessary bead.

The next step is to fuse the bead of glass surrounding the wire into the side or end of the tube. There are two ways of doing this.

In the first method, which is the easiest, a hole slightly smaller than the bead surrounding the wire is opened at the right place (as shown in Plate V, Figure 1 or Plate IV, Figure 2) and the wire dropped down the *inside* of the tube so that the bead rests in the hole with one end of the wire projecting out through it. The bead and the surrounding glass are then heated until they fuse together and a small segment of a bulb is blown with the wire penetrating through it. This method gives the best results, but it cannot be used in sealing in wires which have larger pieces of metal (such as electrodes) attached to the end which extends outside the glass. A simple type of conductivity cell, for example, has large platinum electrodes attached to wires which are sealed into the ends of narrow tubes used as mercury-wells. The Hildebrand type of hydrogen electrode is made similarly. Since it is not easy to attach the electrode to the lead-in wire after it has been sealed into the glass, the bead must be fused into the tube from the outside, and this is done as follows.

A piece of glass rod or tube is temporarily attached to the electrode as a handle. The bead is then held in the open end of the narrow tube and, using a rather

small flame, the two are melted together and then blown out as before. The difficulty in this is that unless the two parts are kept perfectly steady, the wire end projecting through the bead into the narrow tube will come in contact with the inner wall and stick to it—and if that happens the seal can not be blown properly. Aside from this purely manipulative difficulty, the joints are as satisfactory as those made by the preceding method.

II. *Arc-Welding Platinum Electrodes to Platinum Wires*

The method used by the writer for attaching sheet platinum to platinum wire is as follows.

The platinum sheet, cut to size, is laid on the table and the platinum wire placed in position with its end extending about a millimeter on to the platinum sheet. The wire is held down by a lead weight and has a copper wire twisted on the end remote from the sheet. The copper wire leads to the resistance-board on the wall. The other wire from the resistance is wrapped round the top of a lead-pencil, the wood having been partly cut away to make connection between the wire and the graphite. Using a piece of smoked glass as protection for the eyes, an arc is struck between the point of the pencil and the platinum wire where it lies on the sheet. See Plate VIII, Figure 3. With a properly adjusted resistance, it is possible to obtain an arc that will, in a second or two, melt the platinum and weld the wire firmly to the sheet. This must generally be

done before the wire is sealed into the glass, as otherwise the heat of the arc would crack the seal.

III. *Borosilicate to Soft-Glass Joints*

Owing to the difference in expansion, borosilicate glass can not be sealed directly to either lime-soda or lead-glass. Graded seals can be purchased which have "Pyrex" borosilicate glass at one end and lead-glass at the other, and some five or six glasses of intermediate composition in between. Similar graded seals are available for sealing borosilicate glass to quartz. While graded seals can be built up from the appropriate intermediate glasses in the laboratory, there is little point in doing so on account of the trouble involved.

For many purposes, joints made with deKhotinsky Cement or some similar material are entirely satisfactory. For this purpose a tube of each kind of glass must be found of such a size that one fits inside the other as closely as possible. Both pieces are warmed and the smaller one smeared with the cement, after which it is thrust into the larger tube for a distance of 2 or 3 centimeters. If properly made, there will be a continuous film of the cement between the two tubes, with at most only a few air bubbles. If the inner tube does not fit quite snugly, it will be found that after the joint has cooled the cement tends to shrink away from the glass, and leaks develop. When properly made, such joints will remain gas-tight indefinitely.

As an alternative to cemented joints between the different kinds of glass, ground joints can be used.

PLATE XI

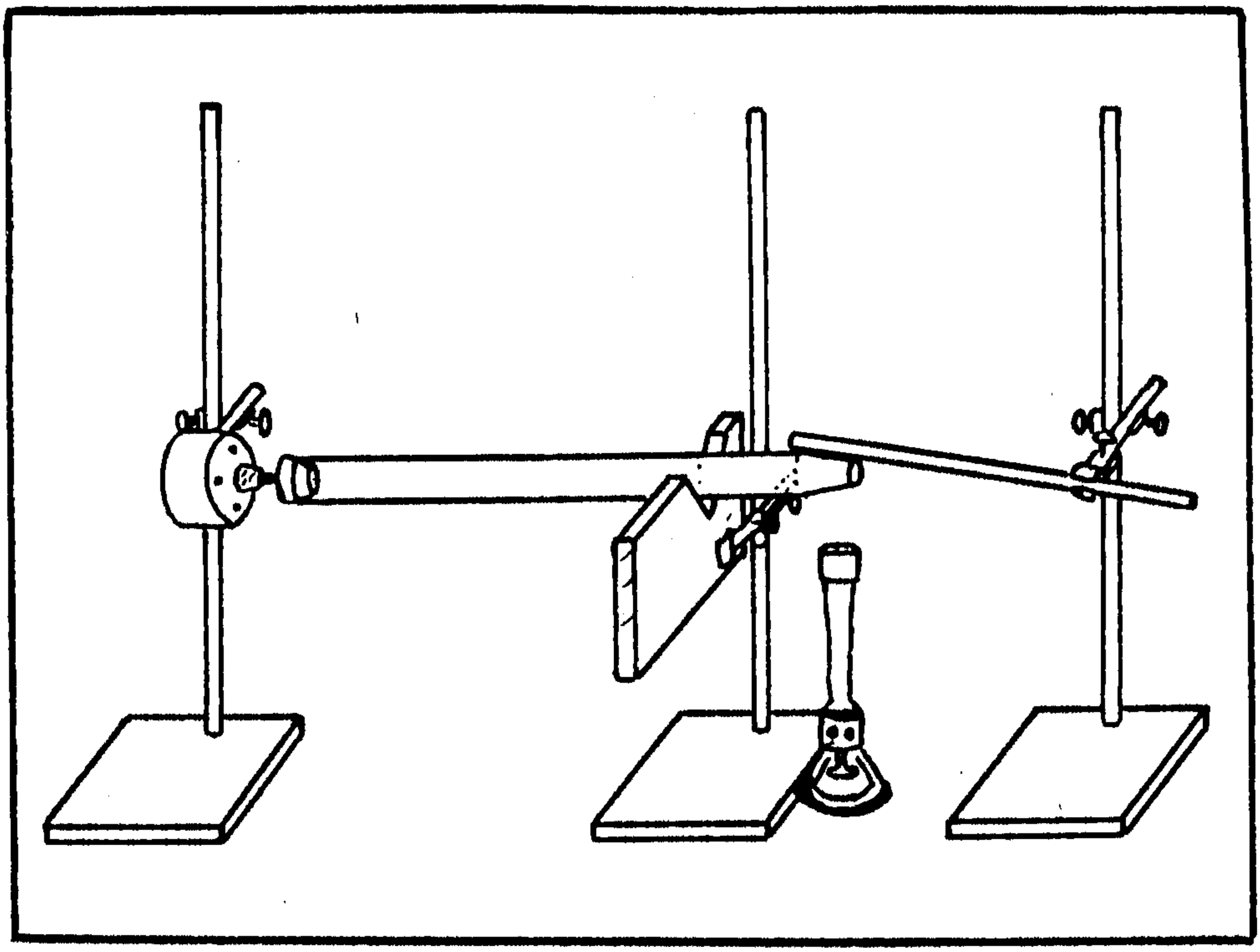

FIGURE 1

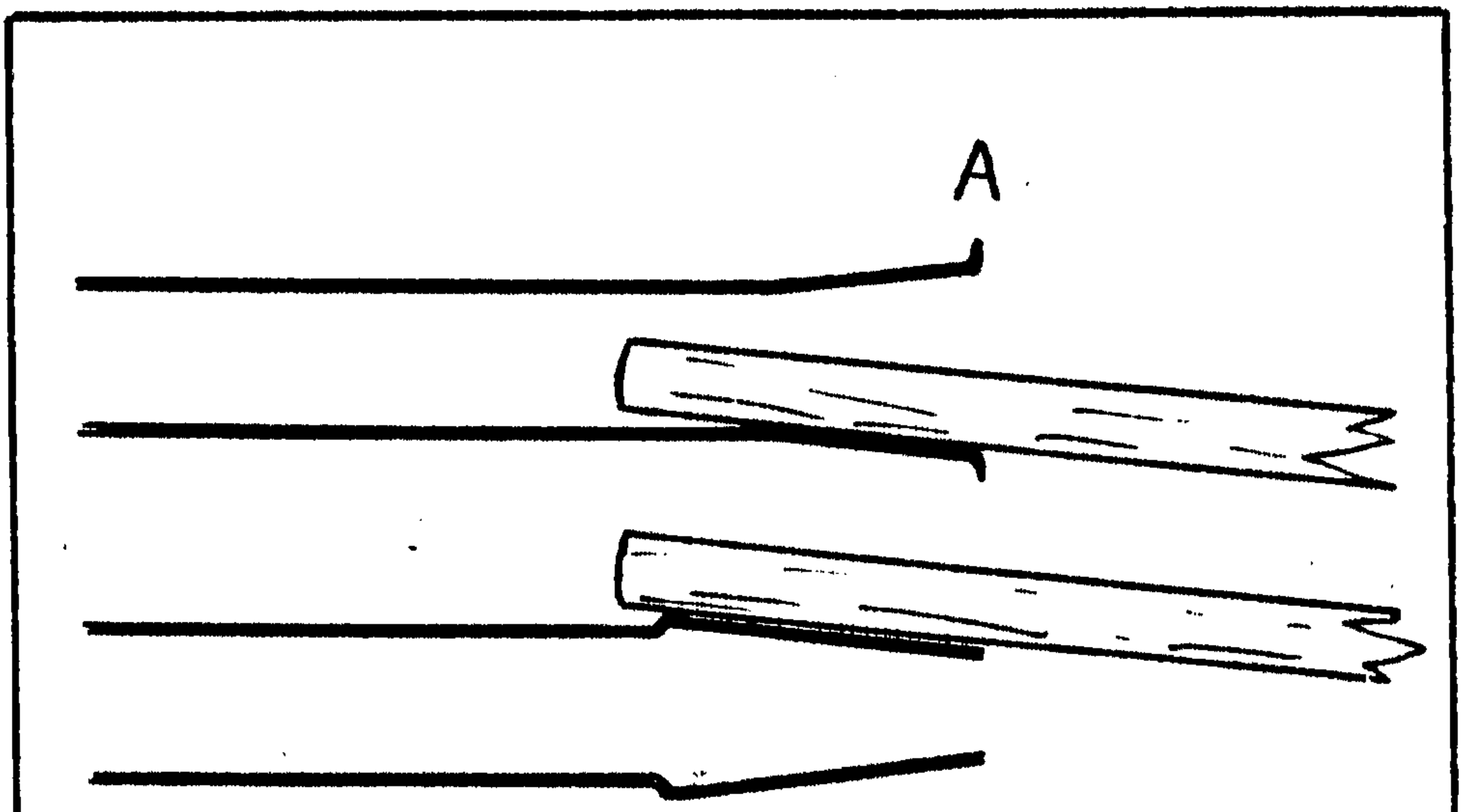

FIGURE 2

IV. *Ground Joints*

Although interchangeable ground joints can be purchased in many sizes and are suited to many purposes, it is sometimes necessary to make a ground joint in the laboratory. The main difficulties of the procedure usually recommended are in retaining a truly circular cross-section while producing the same taper in the two parts. These difficulties are avoided by using the following method. See Plate XI, Figure 1.

A glass tube of the required size is supported near one end in a V-shaped cut in a board and at the other by a one-holed rubber stopper held by a rod in the chuck of a variable-speed stirring motor. The glass tube should be lubricated with a little glycerine where it rotates in the V-cut. An arc-lamp carbon or other carbon rod is held in a clamp at the angle desired for the ground joint and at a height such that it will press either the outside or the inside of the tube to be drawn down or flared. The end of the tube for a length of several centimeters is then heated in the flame of a Meker burner while the tube is rotating at a moderate speed. When the glass begins to soften, the ring-stand carrying the carbon rod is slid, little by little, along the bench so that the rod gradually presses the glass to the desired taper. A blast lamp held in the hand may be used to supplement the Meker flame.

In order to produce the flare shown at A in Figure 2, Plate XI or the bulge shown at B in the same figure, the speed of rotation is increased considerably and the

flame played on the glass until it softens enough to be thrown outward by centrifugal force.

The success of the method depends on the fact that the angle at which the carbon rod is held is not altered by sliding the ring-stand along the table or moving the clamp up or down on the ring-stand.

When the two parts have been brought to the desired taper, they are ground with glycerol and carborundum powder.

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